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PROCEEDINGS

OF THE

AMERICAN PHILOSOPHICAL SOCIETY

HELD AT PHILADELPHIA

FOR PROMOTING USEFUL KNOWLEDGE

VOL. XLVI. JANUARY–MARCH, 1907. No. 185.

CONTENTS.

PHILADELPHIA
THE AMERICAN PHILOSOPHICAL SOCIETY
104 SOUTH FIFTH STREET
1907

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TO THE SECRETARIES OF THE

AMERICAN PHILOSOPHICAL SOCIETY

104 SOUTH FIFTH STREET

PHILADELPHIA, U. S. A.

PROCEEDINGS

OF THE

American Philosophical Society

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VOLUME XLVI

JANUARY TO DECEMBER

1907

PHILADELPHIA
THE AMERICAN PHILOSOPHICAL SOCIETY
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VOL. XLVI JANUARY–APRIL, 1907. No. 185.

Stated Meeting January 4, 1907.

President SMITH in the Chair.

An invitation was received from the Reale Istituto d'Incoraggiamento di Napoli inviting the Society to be represented at the celebration of the completion of the first centenary of its existence on December 31, 1906.

The Secretaries were instructed to express suitably the regret of the Society that the invitation was received too late for the Society to be represented at the celebration.

The decease was announced of Alexander J. Cassatt at Philadelphia on December 27, 1906, æt. 67.

The following papers were presented:

"The Geology of the San Francisco Peninsula," by RODERIC CRANDALL. (See page 3.)

"The Cathodic Precipitation of Carbon," by WILLIAM BLUM and EDGAR F. SMITH. (See page 59.)

The Judges of the Annual Election of Officers and Councillors held on this day between the hours of two and five in the afternoon, reported that the following named persons were elected according to the laws, regulations and ordinances of the Society to be the officers for the ensuing year:

President

Edgar F. Smith.

Vice-Presidents

George F. Barker, William B. Scott, Simon Newcomb.

Secretaries

I. Minis Hays, Arthur W. Goodspeed,
Edwin G. Conklin, Morris Jastrow, Jr.

Curators

Charles L. Doolittle, William P. Wilson, Albert H. Smyth.

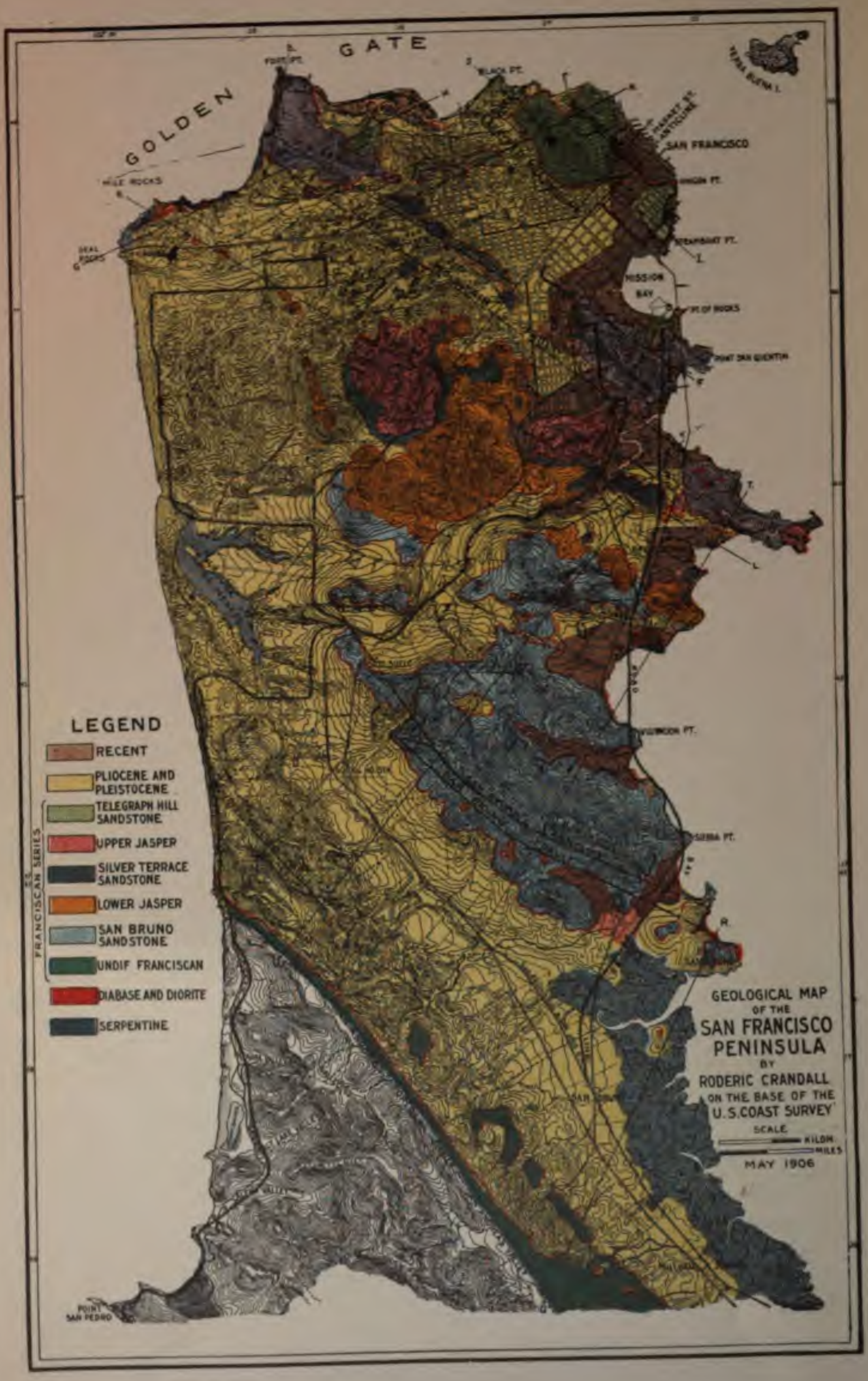
Treasurer

Henry LaBarre Jayne.

Councillors

(*To serve for three years*)

Richard Wood, Samuel G. Dixon,
J. G. Rosengarten, Henry F. Osborn.



GOLDEN GATE
FORT PT.
BLACK PT.
YERBA BUENA I.
MILE ROCKS
SEAL ROCKS
MARKET ST. ANTICLINE
SAN FRANCISCO
RINCON PT.
STEAMBOAT PT.
MISSION BAY
PT. OF ROCKS
POINT SAN QUENTIN
LEGEND
RECENT
PLIOCENE AND PLEISTOCENE
TELEGRAPH HILL SANDSTONE
UPPER JASPER
SILVER TERRACE SANDSTONE
LOWER JASPER
SAN BRUNO SANDSTONE
UNDIF FRANCISCAN
DIABASE AND DIORITE
SERPENTINE
FRANCISCAN SERIES
GEOLOGICAL MAP
OF THE
SAN FRANCISCO
PENINSULA
BY
RODERIC CRANDALL
ON THE BASE OF THE
U.S. COAST SURVEY
SCALE
KILOM
MILES
MAY 1906
POINT SAN PEDRO

THE GEOLOGY OF THE SAN FRANCISCO PENINSULA.[1]

(WITH A MAP.)

BY RODERIC CRANDALL.

(*Read January 4, 1907.*)

INTRODUCTION.

The main points to be covered in this paper will be stated in the beginning. These are:

1. A description of the terranes mapped with an outline of the petrography of each.

2. A description of the structure of the area with the resulting physiography.

3. A general discussion of five points of special interest: The age of the non-crystalline sedimentary rocks of the Franciscan or Golden Gate series; the origin of the Merced series; the origin of the jaspers, serpentines and metamorphic schists. In the general discussion it will be realized that this is the application of information from work done by others to local problems, in an endeaveor to throw any light possible upon some of the complex problems of the Coast Range geology.

The actual field work has been much facilitated by the good maps available. On the whole area the map of the U. S. Geological Survey has been found excellent, the topography of this map being mostly the work of the U. S. Coast and Geodetic Survey. In the city proper the map of Britton & Rey was found very good for street location. The photographs with the exception of three, two of the anticline near San Bruno point and one of the relief map of San Francisco, are the work of Mr. Robert Moran. The three excepted were taken by Mr. Berton Crandall.

[1] A thesis for the degree of A.M., presented to the Department of Geology of Stanford University, April, 1907.

II. Geological Terranes.

There are six geological terranes represented on the San Francisco peninsula.

I. The Montara granite.
II. Franciscan or Golden Gate series.
III. Merced series (Pliocene).
IV. Pleistocene and recent including the sand dunes derived from the Pleistocene.
V. Serpentines.
VI. Igneous intrusives other than peridotite.
VII. Schists.

I. The Granites.—The Montara granite does not properly belong within the area mapped, but it deserves mention in this connection because of its direct relation to the Franciscan series and the problem of the age of the latter. It belongs to the oldest rocks that appear in the Coast Ranges but is considered to be younger than the crystalline limestones and schists that occur exposed further south in these same ranges. The age of the schist and limestone is unknown and the age of the granite is likewise unknown further than that it is older than the Franciscan series, and is considered by Dr. Fairbanks to be older than the granite of the Sierras, which is intrusive in the upper Jurassic sedimentary beds.

II. The Franciscan Series.—The Franciscan series, which is the one of chief interest, rests upon the eroded surface of this granite as exposed on the northwest end of Montara Mountain near Devil's Slide. The lowest beds of the series are conglomerates containing boulders of granite that lie directly on the igneous rock. The petrographic evidence shows that the sandstone is derived mainly from the erosion of this or some similar igneous rocks, and is necessarily arkose.

The Franciscan series proper consists of five beds in the following order.

1. *Coarse Conglomerate* containing large boulders of granite.

2. *The San Pedro Shales.*—These are thinly bedded black shales having a thickness of approximately four thousand feet. This sec-

tion is exposed in the cliffs north and south of San Pedro Point for which they are named. The shale is very similar throughout, being grayish black, close grained and hard. It is in thin layers

FIG. 1.

San Pedro Point, showing the beds called San Pedro shale dipping northeast.

varying in thickness from an inch to twelve or fourteen inches and occasionally interbedded with fine and coarse grained sandstones that grade into granite-bearing conglomerates which are not persistent. The beds weather into oval forms, the outer surface of a lump often being marked with ridges that define the oval forms into which the shale breaks.

3. *Limestones.*—Overlying this shale series is a limestone partially crystalline in general, and wholly so in places, but more commonly interbedded with jasper layers approximating an inch in thickness. This limestone occurs in Calera Valley where it forms several small hills, and it continues intermittently toward the southeast, the largest area being on Cahill Ridge. No work was done upon this limestone but it has been described by Professor Lawson

as showing, microscopically, the presence of many foraminifera and is called by him foraminiferal limestone.[1]

4. *San Bruno Sandstone.*—Above the limestone come the most characteristic beds of the series. These are shales, and sandstones, which occasionally have coarse conglomerates interbedded with them. With the shales are also large accumulations of pyro-clastic materials which are confined to a fairly well defined horizon just below

FIG. 2.

San Pedro shale beds dipping southwest; a point just north of San Pedro Point.

the jasper beds. In mapping, these volcanic tuffs have not been differentiated from the rest of the series. It is the weathering of these tuffs that gives rise to the most of the numerous and varied forms of metamorphic rocks, which, in the field, have been called greenstones.

The larger part of this horizon is made up of sandstone proper, which, when fresh, is a hard, blue gray rock, generally showing but few bedding planes, the dip being only discernible where thin beds of shale are present.

[1] 15th Ann. Rept. U. S. Geological Survey, p. 405.

This phase of the series is well exposed in the large quarries in the city of San Francisco. One just northwest of Ocean View, and another about one half mile south of Ocean View show especially good sections. The black shales that occur in this sandstone are well exposed in the cuts made at Visitation Point and north of there, along the line of the new bay shore road of the Southern Pacific railway.

The top of this sandstone series is a few hundred feet of sandstone that is very generally characteristic wherever found. The noticeable thing is the form in which it weathers, a soft light yellowish gray rock with pink spots throughout it. The persistence of this character of the rock has been noted at the several places where it is exposed, even when the exposures are some distance apart. It is best shown about half a mile east of the Cliff House, but specimens from the southwest side of the San Bruno mountains, and Sawyer's Ridge near San Francisco, and from Alum Rock canyon and San Felipe Valley, in the Mount Hamilton region, are macroscopically identical. It is to be noted here that in all four of these places the horizon is the same, that is directly under the lowest bed of the red jasper.

5. *Jaspers.*—The next group of beds in the Franciscan series is the jasper. This consists of three beds, which in this area, have been mapped separately. At the bottom of the group is the lowest jasper. This is a bed approximating five hundred feet in thickness. Lying upon this are sandstones, shales, tuffs, and lignites with an approximate thickness of four hundred feet. Over this is the upper bed of jasper which is at least a thousand feet in thickness.

These jaspers are thinly bedded flinty layers, varying from a fraction of an inch to an inch in thickness, and very persistent in character. They are dull reddish, stained with iron oxide, but varying in places to green, white and other colors more locally. In places the jaspers are traversed by white veins of quartz or calcite.

6. *Telegraph Hill Sandstone.*—The top of the Franciscan series, as exposed at San Francisco, consists of eight hundred or a thousand feet of sandstones and shales that is very similar to that underlying the jaspers. This sandstone is particularly well exposed in Telegraph Hill where it is quarried extensively. The shales of this

series are also exposed here but are best shown where Second street has been cut through Rincon Hill, from Mission street eastward. In this part of the series the volcanic tuffs are also to be seen but only in small exposures.

So far as is known the Franciscan series is a unit, and though the complete section cannot be crossed continuously, owing to structural features, outside of the unconformity between the two jasper

FIG. 3.

Jointing planes in massive sandstone exposed in a quarry on the northeast side of Telegraph Hill.

beds, which is regarded as local, the series is here geologically a continuous one.

The Franciscan series as a whole is much fractured, folded and metamorphosed, even more so in other regions than on the San Francisco peninsula. This deformation seems to have been general and the unaffected regions are smaller and more local than the affected ones.

The effects of this deformation are shown in the present state of the beds. The peculiar shapes into which the San Pedro shales break are due to the movements to which they have been subjected. The most noticeable effect in the sandstones is the many joint planes

which in an open quarry obscure the original bedding planes. Professor Lawson has attributed these joints to weathering but their occurrence in fresh rock after the same fashion leads to the belief that they are of dynamic origin, though they are much more evident in the wethered beds. In the open quarries, planes along which

FIG. 4.

Slickensided faces in jasper, shown at a quarry on Lobos Avenue near the ocean.

slipping has occurred and small faults from a few feet to a hundred feet, may be observed crossing each other at varied angles and in many directions. In the small faults the sandstone may be seen altered to a thickness from three to ten inches on either side of the fault plane. Secondary silicification is widespread in these sandstones, giving rise to barren quartz veins in places, some of which were the cause of the gold mining excitement on San Bruno mountain some years ago.

The tuffs also show marked effects of regional disturbances, resulting in the formation of dark green, hard, compact rocks, which were termed greenstones in the field until their true character was ascertained. Examples of this rock may be seen in the small islands along the cliffs of the Golden Gate, at Silver Terrace hill and at Mussel Rock.

The jaspers more than any other rocks, show the result of crushing in the contortions and wrinklings of their layers. They seem to be beds of great elasticity, that bend and twist without breaking.

FIG. 5.

Local folding and faulting of jaspers at Stow Lake, Golden Gate Park.

In nearly every place where they are exposed they show either parallel successions of close folds, or wavy structure, which is particularly well emphasized by their thin bedding.

PETROGRAPHY OF THE FRANCISCAN ROCKS.

Sandstones.—The sandstone, in the hand specimen, when fresh, is a bluish gray rock; when weathered it is a dull yellowish brown. In the field this sandstone is characterized by two of its constituents, the small flakes of shale and the presence in certain localities of considerable amounts of brown mica. Slides of this rock from various places are very similar except for the presence of mica, and in nearly all cases show that it is sandstone derived almost entirely from the weathering of an igneous rock—in other words it is an arkose.

The grains are small and angular rather than rounded, set widely

apart in a large amount of cementing material. This cementing material seems partly silicious and partly ferruginous but at times it is calcareous. Most of the grains appear to be quartz, but when optical figures were attempted, on various sections, biaxial figures were obtained showing a portion of them to be feldspars instead of quartz. Plagioclase is present in all the slides and is noticeable by its twinning. In one slide a large angular rock fragment was observed which was composed of quartz and plagioclase. The extinction angle of this plagioclase gave about 18°, placing the feldspars with the acid labradorites or near the oligoclase. Dr. Becker in his monograph on the coast quicksilver deposits, remarks on the uniformity of this arkose throughout the state. He says the typical feldspar is oligoclase with occasionally a more basic one, quartz and orthoclase being in about equal amounts.

One point of interest in connection with this sandstone is the presence of feldspars. As the experiments of M. Daubrée show that pulverized feldspars change to kaolin very rapidly in the water, the conclusion is that these rocks are shallow water deposits.

The presence of the orthoclase and oligoclase with quartz, in the slides, taken with field relations between this sandstone and the Montara granite leads to the conclusion that this granite may be part of this land mass, though it is not necessarily true that this sandstone is all formed from the Montara granite, but from a granite that possibly underlies the whole Coast Range and of which this is a part.

Small fragments of brown mica are often present, and little, long flakes of black shale that appear blue black in ordinary light, but which are not affected by polarized light.

Quartz appears throughout the rock in small veins, traversing it in all directions. These veins are newer than the mass of the rock, but they were formed before the dynamic movements took place, for they give the same wavy and banded extinction that all the quartzes and feldspars do in the main rock mass. The secondary quartz shows fine aggregate texture with each little crystal of the aggregate having its own position of extinction. Secondary quartz of this nature is seen in nearly all of the rocks of the Franciscan series.

Calcite, another secondary mineral, is present and is later than

the quartz, cutting through the rock regardless of previous fractures. The extinction of the calcite is not wavy, due to the fact that it is later than the period of movement.

Slides were made of sandstone from the specimens taken from within four inches of the contact of the serpentine and sandstone at the Presidio and the Potrero. No metamorphism was observed, except for a slight difference in the cementing material, showing that no contact metamorphism has taken place here, even at so short a distance from the serpentine. A slide made from sandstone taken from the face of a small slip zone in one of the open quarries, shows the results of movement in this rock. The cementing material had been changed to a fibrous green mass that was not affected by polarized light. The quartz was all recrystallized into the fine aggregate texture mentioned before, but in some cases the original form or outline of the sand grains could still be seen.

This is interesting to show the amount of metamorphism produced by the intrusion of a large mass of periodotite, and by movement resulting in a small fault.

Tuffs.—The much weathered tuffs appear as dark green or much iron stained crumbly beds, and are well characterized by their popular name of "rotten rock." They are much broken up beds that can easily be dug into with a hammer, and possess no visible bedding planes unless associated with sandstone or shale. This is the form of the rock under ordinary weathering but when metamorphosing agencies have acted upon it, it becomes a hard green rock, with much quartz and has the appearance of a metamorphosed jasper.

Slides were made from this tuff from Baker's beach, Point Lobos beach, Silver Terrace hills, Potrero and several other localities, the best specimens being obtained from Silver Terrace.

At the last named place the tufaceous nature of the rock can be plainly seen in the weathered specimens. In a quarry near Silver avenue and First street the relation of the fresh to the weathered rock is seen. Here there appears to be a dike of green rock intruded into the tuff, but a microscopic examination shows the apparent green dike and the brown tuff to be the same. In a street cut on Railroad avenue near Nineteenth avenue the cause of the meta-

morphism of the tuff is plainly seen in the presence of a dike of diabase which appears to have a width of at least one hundred feet. Further south on Railroad avenue the presence of much broken and contorted jaspers determine the proper horizon of the tuffs.

The specimens for this work were taken from the new Southern Pacific railway tunnel through the hill on Railroad avenue.

In a slide the main part of the rock is a dark green mass that does not react to either ordinary or polarized light. Tests with hydrochloric acid show that it is mainly amorphous silica stained with iron. Set in this groundmass are clear irregular shaped crystals some of which are quartz and some are feldspars. Plagioclases showing banded twinning and wavy extinction are present and the measurement of extinction angles, though not entirely accurate, gave about 18°. Rock fragments were seen in one slide and these were micro-perthite, intergrowth of orthoclase and albite. This with the presence of the untwinned feldspars led to the conclusion that the twinned feldspars belong to the albite group, although the extinction angle is rather high, due perhaps to inaccuracy in measuring a feldspar with wavy extinction. No large amount of ferromagnesian minerals is present, small amounts of a brown mica being the only ones observed.

The quartz of each grain present has been recrystallized into minute aggregate texture, the average size of the new grains being about .02 mm. in diameter. Small patches of the same dark blue shale are present that were noted in the sandstone, as are also secondary quartz and calcite veins.

This tuff that has just been described is from the Silver Terrace hills; those from Baker's beach region show the presence of two other minerals, chlorite or a chlorite-like mineral and irregular masses of pyrite.

The chlorite is present in long fibrous seams and irregular patches. It is strongly pleochroic from dark green to yellowish green. In one slide this mineral appears along a seam in the rock in the form of fibrous spherulites ranged on both sides of the seam, and growing toward the center. Under cross nicols it shows anomalous colors, Berlin blue, yellow and brown, with a wavy extinction that is approximately parallel.

According to Rosenbusch, chlorites are common minerals as secondary products in altered tuffs, being derived from the aluminous members of the biotite and phlogophite micas, pyroxenes and amphiboles. Just what minerals the chlorite in these tuffs was developed from is indeterminable from any slides made, but it represents the presence of some of the ferro-magnesian minerals previous to metamorphism.

The presence of albite, microperthite, orthoclase and quartz places the tuff with the acid group, but not definitely.

This tuff shows three periods of metamorphism: first, the formation of pyrite and chlorite; second, the introduction of the secondary quartz veins, which show recrystallization and wavy extinction, and which have cut through the chlorite; third, the introduction of veins of calcite that do not show wavy extinction and which are later than the quartz.

Jaspers.—The hand specimens of the jasper need little description as they are already well known. Very little petrographic work was done upon them but a resumé is here given of the results of the examination made by Dr. Hinde.[1]

Sections were made from the chert from Angel Island and from the Buri-Buri ridge, San Mateo county. The radiolaria appear as rounded outlines, with diameters of .055 mm. to .3 mm., set in a matrix of silica. The structure is not retained, the walls having graded into the silica matrix. In general the silica of the cast differs from that of the main rock mass, which shows a minute aggregate form.

All the forms were poorly preserved, making the exact determination unsatisfactory, and specific correlation impossible with other known radiolaria. In general the types resemble those from the Cretaceous and Jurassic of Europe. Dr. Hinde has given a partial identification of certain species, and plates illustrating these accompany his paper.[2]

III. Merced Series (Pliocene).—The Merced series is well exposed along Seven Mile beach, presenting a measured section

[1] The Radiolarian Chert of Angel Island, Bulletin Department Geology, University of California, I, No. 7, p. 235.

[2] *Loc. cit.*, p. 240.

over a mile in thickness. The beds are only partially consolidated except locally. The series consist mostly of sands and clays bedded from a few feet to over a hundred feet in thickness. Certain thin conglomerate layers are much harder and more resistant than others; these consist of jasper pebbles and broken shells. This hard conglomerate is well exposed at Mussel Rock and along the ridge southeast of there, lying along and near the Franciscan rocks. There are dark or almost black clay beds in the series and these are the ones that are most fossiliferous. As the upper part of the section is approached the beds are softer and more sandy. There are a few small layers of lignitic material and in the cliffs just south of the Life Saving Station there is a layer of white volcanic ash. Along the cliff this layer of ash has a fairly constant thickness of ten or twelve inches.

Dr. Ashley has described these beds more thoroughly and has given their identification in his paper.[1]

IV. Post-Pliocene.—Above the Merced series lies the Pleisto-

Fig. 6.

Pleistocene and recent deposits overlying the serpentine of the Presidio sill.

[1] Neocene Stratigraphy of the Santa Cruz Mountains, Proc. Cal. Acad. Sci., Series 2, V, 312.

cene, consisting of a thickness of perhaps one hundred feet of partly consolidated clay. Dr. Ashley mentions a thickness of two hundred feet south of Mussel Rock. In the area mapped the thickness of the Post-Pliocene beds was difficult to determine but is probably not over one hundred feet.

The question of the conformity or unconformity of the Pliocene and Pleistocene is one that is yet to be decided and is not evident in this area. No paleontologic work was attempted upon these beds.

V. SERPENTINES.—In the city the serpentines form a prominent terrane; the best exposures for study are in the large hills at the Potrero. The serpentine is found in several places, and is always

FIG. 7.

A conglomeratic effect in serpentine as exposed in a quarry on Potrero Ave., near the railroad.

characterized by the blue green appearance, and by a lack of soil and vegetation over the surface. In the quarries of the Potrero the original peridotite rock may be seen. This appears as large black boulders in the serpentine, giving the appearance of a coarse conglomerate. Each of these boulders is separate from the others and coated with from one to many inches of slickensided serpentine. This shows the breaking up of the peridotite mass and the large

amount of movement that has taken place, due to the increase in volume in the formation of serpentine.[1]

The peridotite is the fresh facies of the serpentine, and has been shown petrographically to be the rock from which the serpentine proper is derived. The other or slickensided facies of serpentine is the one with which nearly everyone is familiar. It is blue to green in the hand specimen, soft and smooth to the touch. It flakes roughly, giving always new slickensided faces showing that there have been movements in every little particle of the rock. There are occasionally varying streaks of a hard brown rock that seems different from the main mass but which petrographically is just the same.

Associated with these serpentines are small veins of magnesite, some of it of the fibrous variety, and some hard and compact. Another rock that is found with the serpentines has been termed "silicious carbonate sinter" by Professor Lawson.

This material is a weathered product of the serpentines. It is a hard, light-colored rock showing lines of silicification throughout. It is believed to have been produced by a leaching of the magnesium, in the form of a carbonate, from the serpentine, with a simultaneous redeposition of the silica present as amorphous silica, and more or less stained with the iron from the original rock.[2] The magnesium leached out probably goes toward the formation of the magnesite veins common in the serpentine. Rock sections show but little except the lines of silicification, as the amorphous silica does not react in the ordinary or polarized light.

Petrography of the Serpentines.

The petrography and a few chemical analyses of the serpentines that are available are of much interest.[3] The description of two facies of the serpentine will be given, the massive facies and the slickensided facies.

[1] G. P. Merrill gives 33 per cent. as the increase of volume due to formation of serpentine by the hydration of olivine.

[2] Knopf, A., An Alteration of Coast Range Serpentine, Bulletin Department Geology University California, IV, No. 18, p. 425.

[3] Dr. Palache has described the serpentines in his paper on the lhezolite serpentines of the Potrero. Bulletin Department of Geology University California, I, No. 5, p. 235.

Massive Facies.—Fresh specimens of the massive facies were taken from the Potrero and the Presidio.

From the Potrero no sections were obtained in which serpentine was not present. Other constituents or original minerals present in the peridotite are as follows: orthorhombic pyroxene énstatite, monoclinic pyroxene diallage, olivine, magnetite, and chromite. These constituents give the serpentine the name of lhezolite, the original rock being a peridotite.

The largest constituent of this rock appears to be the pyroxene diallage. The crystals show no definite form but are in long irregular shapes, possessing marked cleavage in the long direction. Basal sections occasionally show the parting characteristic of diallage. The relief is medium and the crystals are colorless in ordinary light. Under cross nicols the colors are high, most commonly upper first and second order. The extinction angle varies with the different sections from 18° up, the largest angle measured being 48°, the commonest about 43°.

Enstatite, the orthorhombic pyroxene, occurs in lesser quantities than the diallage and is indistinguishable from the diallage in ordinary light, the relief, color and form of the sections being similar.

Under cross nicols the colors are low, blue grey of the first order in a slide of proper thickness. Being orthorhombic the extinction is parallel and so may be distinguished from the diallage.

In one section fine multiple twinning was observed in the enstatite; the extinction was almost simultaneous for the two sets of lamellae, making it not especially noticeable. The lines of twinning made an angle of over 30° with the direction of extinction, but because of lack of similar sections the face of twinning was not determined. Rosenbusch remarks that the twinning of enstatite is not common. Both the pyroxenes showed in most of the slides with serpentine formed through them with lattice work effects.

Olivine is present only in small irregular grains wholly surrounded by serpentine due to its having weathered faster than the pyroxenes.

In ordinary light it is clear and colorless and is distinguished from the pyroxenes by its higher relief and lack of cleavage. In

polarized light its colors are high, being upper second in general. Groups of these olivine grains situated together would often extinguish simultaneously, showing that the original crystals of this mineral were quite large.

Magnetite in black patches and chromite in brownish black masses were present, scattered through the serpentine and as inclusions in the diallage.

The pyroxenes showed marked wavy extinction, due to the amount of pressure and movement to which they have been subjected.

The serpentine appears yellowish and greenish in ordinary light and surrounds the grains of olivine and in lattice work forms through the pyroxenes. It seems stained with iron to a considerable extent. In polarized light it is blue grey with a felted appearance and compensatory extinction.

Slickensided Facies.—The slickensided facies is similar to this except that none of the original minerals remain, the serpentine derived from the pyroxenes being the same as that derived from the olivine.

ANALYSES OF SERPENTINE.

Locality.	Presidio.	Angel Island.	Mt. Diablo.
SiO_2	39.60	42.06	36.57
Cr_2O_3	.20		.33
Al_2O_3	1.94	2.72	95
Fe_2O_3			7.29
FeO	8.45	2.88	.37
MnO			.10
NiO			.31
CaO			.14
MgO	36.90	39.53	40.27
K_2O			trace
NaO			.31
H_2O above 100°	12.91	12.04	12.43
	100.00	99.23	99.07
Analyst.	Dr. Easter.	F. L. Ransome.	Dr. Melville.

The fresh facies of the peridotite from the serpentine mass of the Presidio gave sections that showed the presence of no serpentine at all. There were two main minerals present with slight amounts of the same accessory minerals, as seen at the Potrero. Diallage and enstatite, the same as described from the Potrero, are present, the last named mineral in subordinate quantities. No oli-

vine was found at all, making this rock a true pyroxenite. That the main mass of the serpentine of the Presidio is not derived from a pyroxenite will be seen from the chemical analyses following.[1]

Analyses.—There is a marked similarity between the analyses of the serpentine from three distinct localities.

Turner mentions the gradation from peridotite to pyroxenite in the serpentine of Mt. Diablo. The analysis of the Presidio serpentine shows it to be an olivine bearing rock, so that the pyroxenite may be considered a local variation in the main peridotite magma.

VI. Igneous Intrusives.—The igneous intrusives cut the jaspers, sandstones and the associated serpentines of the Franciscan series. They consist of several closely related varieties.

The most important of these intrusive rocks occur in the Potrero, where they are intruded in the serpentine. Of this particular

Fig. 8.

Remnant of a diabase dike intruded into the serpentine of the Potrero sill.

intrusive there are two facies: hypersthene diabase, and hornblende diabase or epidorite. The others of these intrusives from elsewhere than the Potrero are hornblende diabase, amygdaloidal diabase and

[1] These are taken from a paper of H. W. Turner, Journal of Geology, VI, 487.

hornblende diorite. The hand specimens are all more or less alike —hard green rock of close texture, only occasionally varying to a coarse grained rock in which the plagioclase and ferro-magnesian minerals are easily distinguishable with a hand lens. These will be described in the order given.

Petrography of the Igneous Intrusives.

Hypersthene Diabase.—The hypersthene diabase is the freshest rock of the series, and has the following constituents: hypersthene, malacolite, labradorite, hornblende, magnetite and ilmenite. The orthorhombic pyroxene, hypersthene, is present in small quantities. It is reddish, with a high relief, the pleochroism being fairly strong from red to greenish. The ray $\mathfrak{a}$ is red and the ray $\mathfrak{c}$ green. This occurs in large irregular prisms without any definite boundaries.

The hypersthene is characterized by parallel extinction. Around the border may be seen the growth of fibrous hornblende as in the malacolite. Some of the crystals showed a dark appearance due to the presence of small black rods of an unknown mineral. Besides the hypersthene are large irregular shaped crystals of a colorless augite, probably malacolite. In ordinary light it is clear and colorless with a medium relief. Under cross nicols the interference colors are about orange of the first order and the extinction angle is 45°. Twinning was observed.

The interesting thing in connection with the hypersthene and the malacolite is the derivation of secondary hornblende. Crystals of this colorless augite show the growth of pleochroic hornblende all about the border, noticeable in ordinary light, but in polarized light the hornblende has much higher colors. The cleavage of the hornblende is parallel to that of the augite but is more sharply marked. In a crystal with secondary hornblende of this character the extinction angle of the hornblende was 11° while that of the augite was 43°.

The hornblende is in crystals that do not show their derivation. It is in irregular allotriomorphic patches with a greater length in the direction of the cleavage. The pleochroism is from yellow to yellowish green to dark green, corresponding with the axes, $\mathfrak{c}$, $\mathfrak{b}$, $\mathfrak{a}$, with an absorption scheme $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$. The extinction angle, $\mathfrak{c} : c' = 17°$.

The texture is typically ophitic, the feldspars are long and lath-shaped and idiomorphic with regard to the other minerals. Twinning is common and measurements of extinction angles in sections of equal illumination gave 44°, placing them between labradorite and anorthite. The feldspar shows wavy extinction in all cases.

Ilmenite is present in black irregular patches surrounded by the derivative mineral leucoxene. The magnetite shows borders of thin red translucent hematite. These both occur as inclusions in the other minerals, feldspars and pyroxenes.

Hornblende Diabase.—The hornblende facies of the hornblende diabase does not show any hypersthene or malacolite, but only hornblende, idiomorphic feldspars and the accessory minerals magnetite and ilmenite. Since we saw in the previous description that the hornblende was derived from the hypersthene and malacolite, then in this rock we may consider all the hornblende as secondary, making the rock a true epidiorite.

At a certain outcrop on the top of the Potrero hills, just east of the end of Twenty-fourth and near Rhode Island streets, schistose structure is developed so that the hand specimen shows it quite plainly. In a section this schistosity is not quite as noticeable, but the results of pressure are evident. There is a new mineral, some blue soda-bearing amphibole, developing in long, slender, fibrous needles around the edges of the hornblende. This mineral is considered to be glaucophane, but owing to the minute size of the crystals no optical tests were attempted. In a section of hornblende that is pleochroic from yellow to green, the glaucophane is pleochroic from colorless to blue.

Intruded in the tuffs of Silver Terrace is a dike of hornblende diabase or epidiorite. The texture of this rock is ophitic and the constituent minerals are hornblende and labradorite feldspars, with the accessory minerals, ilmenite and magnetite, as described in the hornblende diabase from the Potrero. Three secondary minerals are present, quartz and intergrowth of epidote and clino-zoisite. The quartz is in fine seams with the usual aggregate texture. The epidote and clino-zoisite occur in long fibrous or columnar aggregates. In the seams the columnar texture is most common. The crystals are small and colorless but not clear and in ordinary light

the two minerals are indistinguishable. In polarized light the epidote shows grey colors of the first order but the clino-zoisite shows upper first and second order colors. These minerals are plainly secondary but whether they are derived from the alteration of plagioclase is not apparent. When these veins are cut at right angles to the columnar length of the epidote crystals, minute cross sections are seen. These aggregates are composed of such small crystals that the compensating extinction gives the whole section a grey appearance that does not change in polarized light, with a low power objective.

Amygdaloidal Diabase.—From the north side of Visitation Valley two outcrops in place give specimens that, though badly weathered, show hornblende and feldspars. One of these rocks shows the hornblende going to chlorite in most of the slides. The chlorite is green and yellow, with a similar color in polarized light. Titanite is present in this rock in rounded grains showing rough relief and irregular cleavage cracks. In polarized light the interference colors are third order and higher, with an extinction angle that is not consistent. Near the south side of the entrance to Visitation valley is an iron stained rock that looks like a weathered conglomerate in the field. Sections of this show it to be an amygdaloidal diabase. The texture is ophitic in the lath-shaped feldspars in a groundmass of allotriomorphic hornblende. A few large crystals of feldspar occur, none of which show twinning, though most of the small ones do. The extinction angles obtained were 18°, placing them near the acid end of labradorites. The hornblende has large cavities filled with calcite mainly, but chlorite and some iron mineral are present also. The chlorite is green but non-pleochroic; in polarized light it shows blue and brown. The iron mineral is a dark reddish brown with a slight metallic lustre.

Hornblende Diorite.—A specimen of rock from the southwest side of the San Bruno mountains shows hornblende and plagioclase but without ophitic texture. The hornblende and plagioclase are the same as those already described, but it contains two new secondary minerals, spinel and titanite.

Spinel is present in large quantities, in rounded irregular grains with high relief and rough surface. Being an isotropic mineral it remains dark under cross nicols.

Titanite is present and appears somewhat similar to the spinel in ordinary light except that it is very faintly pleochroic from colorless to yellowish brown. Under cross nicols it may be distinguished from the spinel by its high interference colors. In this rock much of the hornblende has altered to chlorite, the latter being present as pseudomorphs after the former. It is pleochroic from yellow to green and hardly distinguishable from the hornblende in ordinary light. Under cross nicols, the hornblende shows second order colors, while the chlorite is greenish or blue with varying extinction. This is more clearly exemplified in the rock of the north side of Visitation Valley than in this one.

VII. Schists.—The schists are all of a blue amphibole (glaucophane) variety. There are various grades from a schistose sandstone to a fine glaucophane rock.

Typical of this group is a schist from one mile east of Baker beach along the Strait. It shows nothing but fibrous masses of pleochroic blue amphibole, without any other minerals. The hand specimen is soft, blue, talcose looking rock, that might easily be mistaken for serpentine, but there was no serpentine present in the slides. This rock may be an altered clay shale.

Petrography of the Schists.

Basic Glaucophane Schist.—From the beach along the Strait a mile east of Baker beach come two other schists, one basic the other acid. The basic schist is a very dark rock and does not show its schistose nature. The slide contained the following minerals: hornblende, glaucophane pseudomorphed after hornblende, lawsonite, pyrite, and ilmenite. The hornblende was present only in remnants, the main part of the crystals being glaucophane. The pleochroism of the hornblende was from yellowish green to dark green but much mantled by the strong blue and violet of the glaucophane.

The elongation of the glaucophane was parallel to $\mathfrak{c}'$. The pleochroism was from colorless to violet, to blue, with an absorption scheme $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The extinction of the glaucophane varied only a few degrees from parallel while that of the hornblende in the same crystal was about 13°.

Lawsonite is present in rectangular prisms with elongation paral-

lel to c′. In ordinary light it is colorless and non-pleochroic, the relief is fairly high, with a slight cleavage in the direction of elongation. In this section the colors are upper first and second order, but in basal sections the colors and relief are not so high. The lawsonite is idiomorphic with regard to the hornblende and glaucophane.

Pyrite and ilmenite occur in irregular masses as inclusions in the other minerals. Secondary quartz veins traverse the sections.

Considering the minerals now present and the texture of the rock it seems probable that it is an altered form of hornblende diabase, the glaucophane having developed from hornblende and the lawsonite having been formed by hydration of basic feldspars.

From this same locality (a mile east of Baker beach) is a light blue fissile schist that contains two minerals, a blue soda-bearing amphibole, undetermined, and minute amounts of lawsonite scattered in the interstices between the amphibole fibres.

Acid Glaucophane Schist.—The more acid schist has the following minerals: glaucophane, a groundmass that is quartz or a mixture of quartz and feldspars, large cubes of pyrite, chlorite, titanite, white mica and a mineral determined as andalusite. The glaucophane is present in large elongated crystals with indefinite end boundaries. The pleochroism is very strong, the section being cut parallel to the direction of schistosity while the blue to violet pleochroism is most common. The quartz or feldspars, without twinning, make up the large part of the rock. This is most likely all quartz, being of a fibrous nature, and the fibres are often much twisted and distorted.

The cubes of pyrite are perfect and have affected the deposition or the recrystallization of the quartz, so that the quartz has formed in fibres, so arranged that they appear attached to the pyrite cubes, with the long axes at right angles to the faces of the cubes.

Chlorite occurs in small yellowish green patches scattered irregularly throughout the quartz, showing anomalous colors under cross nicols.

The titanite is found mainly as small irregular inclusions in the glaucophane, some also being seen in the quartz.

There is some white mica with the quartz. In ordinary light

its index of refraction in one direction is nearly the same as that of quartz, but in another position of rotation it shows a slight absorption along the cleavage lines which are parallel to its length. Under cross nicols the colors are high, at least third order, and somewhat irridescent. The last named mineral andalusite, is in radial aggregates with a marked cleavage parallel to the length and slight cross cleavage. It is nearly colorless in ordinary light and with a relief higher than that of the quartz, but lower than the titanite. In polarized light its colors are low, blue grey of the first order with right angle extinction.

It is worthy of note that though this schist is quite silicious, neither garnets or lawsonite have been developed. If the rock had a soda-bearing feldspar it may be that in the formation of the secondary minerals, after the soda had been removed, the remainder of the feldspar constituents formed this aluminium silicate.

Quartz Glaucophane Schist.—The other schist to be described is a quartzose glaucophane schist from about one mile northeast of Lake Merced. There are three minerals present: quartz, glaucophane, and white mica. The rock shows its nature in the hand specimen, appearing as a hard blue quartzite with a suggestion of schistosity.

The main mass of the rock is recrystallized cloudy quartz with fine aggregate texture.

Fine needles of blue glaucophane appear developed with their long axes parallel to the direction of schistosity. The length of these needles is considerable in proportion to their width. Measurements gave a maximum length observed as .18 mm. with an average of .10 mm. The average thickness was about .01 mm. with a maximum of about .05 mm. This shows that these needles are mostly thinner than ordinary rock section, so that pleochroism and interference colors were, for the most part, much obscured. The pleochroism of this glaucophane was from colorless to violet to blue with an absorption scheme of $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. The extinction angle $\mathfrak{c} : \mathfrak{c}'$ is quite small, a maximum of 8° being observed. Ilmenite and pyrite are present in very minute cubes. The cloudy appearance of the quartz may be caused by the dissemination of these fine particles of iron throughout.

White mica is present, intergrown with the quartz, and is noticeable by the marked difference of relief in one position of rotation. In polarized light the colors are third order or higher.

Small veins of secondary quartz appear in the section. These show the same aggregate texture and wavy extinction as the other quartz, but may be distinguished in ordinary light by their clear and colorless appearance, as contrasted with the clouded appearance of the quartz of the rock proper. Without exception the size of the individuals of the aggregates is much larger than those of the other quartz. The average size of the grains of quartz in the main rock mass was about .02 mm. in diameter.

Further careful search may reveal schists not mapped, but such areas would not affect the structure of the region as worked out. The relations of the schists and other rocks will be considered further on in the paper.

III. Areal Distribution.

In the areal distribution the geologic order of terranes followed in the descriptive text is not adhered to. The distribution is best

Fig. 9.

Recent sand dunes near Golden Gate Park. These are derived from the Pliocene and Pleistocene deposits.

shown upon a map, and for this purpose a colored map, with necessary legend, is appended.

Merced Series.—The series that deserves first mention here is the Pliocene, Pleistocene and the derivative sand dunes. These cover the largest part of the area mapped, and because of the widespread distribution of the æolian sand, give the area the appearance of hills almost buried by sand.

The Merced series proper is confined to the long low valley lying between the Buri-Buri ridge and San Bruno mountains. The series lies upon the old Franciscan rocks near Mussel Rock and from there rises to the top of Buri-Buri ridge, follows southeast along the trend of the ridge to about two miles northwest of Millbrae, where it drops into the low hills and appears on the low lying hill to about two or three miles southeast of Millbrae. The complete southeast extent of this series is not shown on the map. Below Millbrae the streams have cut through this series exposing the underlying rocks showing that it appears only as a thin edge and that it is probably chiefly wind-blown material.

A point of interest in this connection is the exposure of the Franciscan rocks on the fronts of the steep hills west of Millbrae and of Baden. In the stream bottoms that run between these hills and in the circular-shaped basin behind them the Merced beds are in place.

Going northward along seven mile beach nearly the entire thickness of the series is exposed tilted toward the northeast. Just south of the Life Saving Station the beds disappear under the Pleistocene formation. The northeast line of the contact with Lake Merced to South San Francisco is not exposed, the rest of the eastern contact from South San Francisco to south of Millbrae, is determined by the marsh line. The obscuring of this contact along San Bruno mountains is caused by the Pleistocene materials which have been blown up against San Bruno mountains about to the five hundred foot contour in places. North of San Bruno mountains these sands cover most of the city proper, obscuring the underlying geologic structure in many places. This formation merges into the recent deposits along the flats.

San Bruno Sandstone.—The formation of next importance in

distribution is the lowest sandstones and shale beds of the Franciscan series which is represented in San Bruno mountains and which for purposes of differentiation in this paper is called the San Bruno sandstone. It is not definitely known what place this sandstone has in the Franciscan series as compared with the sandstones and shales exposed at San Pedro Point, but it appears as if the lowest part of the mountains exposed at Sierra Point was the equivalent of the middle or upper section at San Pedro.

This sandstone and shale form San Bruno mountains and the parallel ridge northeast of Guadalupe Valley; the hills known as Columbia Heights; University Mound in the southwestern part; and the southwestern part of San Miguel Hills, partly covered by the sands and disappearing under the lower jaspers. This sandstone appears in only one place north of the exposures mentioned, and that is at the Cliff House and around Point Lobos to within about a mile of Lobos Creek.

Jaspers.—The formation that overlies the San Bruno sandstone is the lowest jasper bed. This bed of jasper lies directly upon the San Bruno sandstone along the cliffs north of Golden Gate Cemetery. It disappears under the æolian sands and is exposed in only one or

FIG. 10.
Local folding in jasper exposed in a quarry at Golden Gate Park.

two quarries near Point Lobos avenue until Golden Gate Park is reached where it is seen in Strawberry Hill, and one of the smaller hills there that has a wooden cross erected upon it. This jasper forms the crest of the ridge of hills in Sunset district, being exposed only from M to S streets. Continuing, this formation makes up the portion of the San Miguel Hills known as Sunnyside Addition, and extends around the east and north side of those hills almost to Valencia street. On the east side of the railroad tracks it appears in the southwestern part of Holly Park and in irregular areas on the northeastern side of University Mound. On the hills just north of Visitation Valley and west of Railroad avenue the entire thickness of the bed is seen. Two small hills of this jasper occur, one on either side of the entrance to Visitation Valley. Their relations are explained in the discussion of the structure.

Silver Terrace Sandstone.—Lying between the lower and the upper jasper bed is the Silver Terrace sandstone which consists of a bed of sandstone and some tuffs which, together, have a thickness of about five hundred feet. The tracing of the Silver Terrace sandstone and the associated tuff is much more difficult than tracing the jaspers. The full thickness is exposed dipping into the northeast from a point about a half mile east of Lobos Creek to a point about a half mile northeast of Lobos Creek where the upper jasper is exposed in a quarry on the Presido. It is present as an erosion remnant in Golden Gate Cemetery, but does not appear between that place and Blue Mountain. It can be traced around the west and southwest sides of Blue Mountain and Twin Peaks, and it crosses a gap between the latter place and Sunnyside Addition, and continues around the eastern side of Twin Peaks to Buena Vista Park. Erosion remnants cap the hills southeast of Buena Vista Park, Castro street hill and Dolores street hill. In the eastern part of the city it passes through the gap between Bernal Heights and Holly Park and forms the Silver Terrace hills. The sandstone forms a floor upon which rest the Hunter's Point serpentines and the two small hills southwest of Hunter's Point. On top of the serpentine forming Hunter's Point hills, is a small area of conglomerate belonging with this sandstone.

Upper and Lower Jasper Bed.—The Silver Terrace sandstone

is overlain in some places by the upper jasper bed, notably at Blue Mountain, Twin Peaks, and at Bernal Heights. It occurs in several places at the Presidio quarry, near Masonic Cemetery, on the extreme end of Hunter's Point.

Telegraph Hill Sandstone.—A sandstone called Telegraph Hill sandstone composes all the hills in the business portion of the city, Russian Hill, Telegraph Hill, Rincon Hill, Lone Mountain, Lafayette Hill, and is exposed beneath the serpentine at the Presidio, and both under and over the serpentine at the Potrero. It does not appear on top of the jasper anywhere in the city except at the Potrero, and nowhere else is its relations to the Franciscan series shown. Elsewhere in California, so far as the writer's observations go, the Cretaceous overlies the jaspers, but there have been no fossils found here to show that this Telegraph Hill sandstone belongs to the Cretaceous, and as it resembles the San Bruno sandstone petrographically and macroscopically, it is regarded as a sandstone belonging to the Franciscan series and overlying the jaspers.

Serpentines.—Across the city in a northwest-southeast direction from the Presidio to the Potrero and Hunter's Point is a line of irregular areas of serpentine. This line of serpentine is geologically continuous, though it does not appear so on account of the intervening sandstones and æolian sands.[1] The proof of this continuity rests upon the field evidence and the petrographic similarity of the serpentine. That from the Potrero was found to be a lhezolite serpentine, while that from the Presidio was found to be a pyroxenite, but, as remarked in the previous discussion of the rocks, the chemical analysis shows that olivine must be present. The Presidio rock must also be a lhezolite serpentine as is that from the Potrero. Chemical analysis would prove this point beyond a doubt. There are a few small areas of serpentine in other places, namely, in the hills at South San Francisco, Buena Vista Park, Castro street hill, Islais Creek near Holly Park, University Mound, and at several other localities.

Igneous Dikes.—The igneous dikes are present as intrusions in the serpentines of the Potrero and Hunter's Point, in the Silver Ter-

[1] Lawson, A. C., Geology of the San Francisco Peninsula. 15th Ann. Rept. U. S. Geological Survey, p. 445.

race sandstones and tuffs, and in the San Bruno sandstone in a number of places. These dikes are on the north side of Visitation Valley, near Railroad avenue, and near the entrance to the valley, and also on the southwestern slope of San Bruno Mountain, and in the little hills in the marsh, one and one half miles south of South San Francisco.

Schists.—The schists of San Francisco come mainly from one area along Golden Gate Strait between Point Lobos and Lobos Creek. The quartzose glaucophane schist described comes from the San Miguel hills about one mile north of Ingleside Race Track. The biotite schist is from just north of the entrance to Visitation Valley.

IV. Structure.

Main Faults.—The structure of San Francisco peninsula is complex but controlled in general by three main faults. The type of structure is the same as that which characterizes other parts of the Coast Ranges. These are dominant fault lines, with a general northwest and southeast trend. Parallel to these faults are the major lines of folding and minor lines of faulting. Making almost a right angle with these lines are the minor lines of folding.

Lone Mountain Fault.—Lone Mountain fault is the first of the three main faults which control the geology and topography of the San Francisco peninsula to be considered, as it crosses the city from the Presidio to Hunter's Point in a straight line. This fault may be seen only in the cliff near the Presidio. The line can be traced across the city only by the topography and by the areal distribution of the rocks. It is this line which determines the northern limits of the jaspers (excepting that at the Potrero), and the southern limit of the Telegraph Hill sandstone. As the jasper does not appear again north of this line, it is believed that the downthrow of this fault is on the northeast. This is also substantiated by the presence of a very closely compressed syncline, with its axes parallel to the fault and apparently developed by the slipping of the fault block. The throw of this fault is not known, but it is judged to be between 800 and 1,000 feet.

San Bruno Fault.—The second fault is the San Bruno fault. This is clearly a thrust fault with the upthrow of perhaps 1,500 feet

on the northeast side. It is not quite straight but enters the area on the west between the Ocean House and the Life Saving Station, follows a southeast course swinging slightly toward the north as it

FIG. 11.

Jasper remnant resting against sandstone at the point where the Lone Mountain fault cuts the cliffs near the Presidio.

reaches the bay one half mile north of San Bruno Point. The crescent shape of the San Bruno hills is apparently directly related to the form of this San Bruno fault line.

In connection with the upthrust of the San Bruno block, an anticline has been produced parallel to the axis of the fault. At the point where the railroad turns directly west, leaving the city near Ocean View, a topographic saddle has been formed by the breaking down of this anticline. In places this San Bruno fault distinctly affects the topography: a line of low hills along the southwest side of the ridge have jasper remnants exposed on their summits, showing that they are geologically above the top of the San Bruno mountain. The anticline developed by this fault may be seen quite

plainly in two places, near Ocean View and on the bay shore north of San Bruno Point.

San Andreas-Portola Fault.—The most important fault line on the San Francisco Peninsula is the San Andreas Portola fault. It is plainly discernible in the bluffs at Mussel Rock, and from there it runs toward the southeast through San Andreas and Crystal Springs Lakes. This same fault continues to the southeast through the Santa Cruz quadrangle, where it is known as the Portola fault. This is one of the main lines of weakness in the Santa Cruz mountains, and it has been the line of movement at various times. There have been at least two important movements along this fault line,

Fig. 12.

A partial view of the anticline at San Bruno Point showing the sandstone and shale beds dipping northeast.

for the Franciscan sandstone lying northeast of the line is geologically higher than that on its southwest side. Since the movement that caused this dislocation of the Franciscan rocks there was another movement after the deposition of the Merced series which resulted in the tipping of the Merced beds toward the northeast. The steepness of the dip of these rocks increases from Lake Merced southward to Mussel Rock. This second movement brought the Franciscan beds on the northeast side into a position but slightly

lower than their original one, and there has been an apparent development of a minor syncline on the south side of San Andreas Lake parallel to the fault line in places, while the Franciscan beds on the north side of the lake dip sharply to the southwest. The total throw of this fault is indicated by the amount that Franciscan beds on the northeast side of the fault are lower than those of the same horizon on the southwest side, and that is about 500 feet.

FIG. 13.

The San Bruno anticline exposed in the cliffs one mile north of Point San Bruno.

This displacement has been spoken of here as a single movement, but it must be taken as the algebraic sum of all the movements up to the present time rather than as a single movement. That the upthrow of this fault is on the northeast side is confirmed by the evidence in the Santa Cruz quadrangle where the Franciscan beds in Black Mountain are higher than the Miocene beds southwest of the fault.

Minor Faults.—Of the minor faults there are only two worthy of consideration; these are the Visitation Valley and the Wood's Gulch faults.

Visitation Valley Fault.—There are likewise two minor faults parallel to these main fault lines and possibly a third one. The

first of these has resulted in the letting down of the sandstones on the southwest side of the hills known as University Mound, and the formation of Visitation Valley. At the entrance of the valley are two little jasper remnants that have been faulted down. The line of faulting is approximately parallel to Visitation avenue, passing between the two ridges of jasper in the northeastern end of the valley.

Guadalupe Valley is parallel to this line but since it is entirely in San Bruno sandstone it is not certain whether or not its structure is the same as that of Visitation Valley. The dips of the beds on the northeast side of the San Bruno mountains are very much steeper than those on the southwest side of the ridge. This leads to the belief that the Guadalupe is a fault valley, though definite proof has not been found.

Wood Gulch Fault.—In the Merced series about one mile north of Mussel Rock there is another minor fault having a downthrow of some eight hundred feet on the southwest side. There are other small faults in the Merced beds with displacements of twenty-five feet and more, but none of them are important.

The deformation of the Merced beds shows that the San Andreas faults are of post-Pliocene age but the age of the faults across the city of San Francisco from the Presidio to the Portrero (Lone Mt. fault) and at San Bruno Mountain may or may not be of the same age. The greater maturity of the topography in the city hills and on San Bruno Mountain suggests, however, that these faults are both older than the San Andreas-Portola fault.

Folding.—This area has been folded into three blocks which are considered in the order of their importance.

Merced Block.—The area occupied by the Merced beds between Buri-Buri Ridge and San Bruno Mountain is in the form of a slight syncline; this is formed as the result of a block tilted toward the northeast by a thrust fault on the southwest side.

San Bruno Block.—Between San Bruno fault and Lone Mountain fault is the anticlinal fold, already noted and parallel to the San Bruno fault. Otherwise the whole block is simply tilted toward the northeast, the dips becoming steeper shortly before reaching the Lone Mountain fault.

Lone Mountain Block.—North of this fault line the folding is more complex. Parallel to the fault is a closely pressed syncline, called the Lone Mountain syncline, which can be followed from near Thirteenth and Market streets to the Calvary Cemetery, and, judging by the structure exhibited by the sandstone underlying the serpentine at the Presidio, it extends still further. Serpentine is exposed in different places, following the bedding planes of the sandstone, dipping toward the northeast or southwest, according to the side of the synclinal axis that it is on, showing that it is present as a true sill.

Major Folds.—Passing to the northeast of this syncline, the dip of the beds becomes less, averaging about 30° until Lafayette Hill is reached. From there they arch in an anticlinal dome to Russian

FIG. 14.
Bedding of shale in Telegraph Hill series; the exposure on Second street.

Hill and California Street Hill, in what is called the Lafayette Hill anticline. Between Russian Hill and Telegraph Hill is a syncline, the axis of which is closely followed by Montgomery avenue, which is called the Montgomery avenue syncline.

Minor Folds.—Lines of minor weakness are represented by a syncline through Rincon Hill, called the Rincon Hill syncline, an

anticline between the hill at Black Point and Russian Hill, the Black Point anticline, and an anticline between Rincon Hill and California Street Hill, called the Market street anticline. There

FIG. 15.
Local folding in Telegraph Hill sandstone; exposed in a street out on Jones street, near Vallejo.

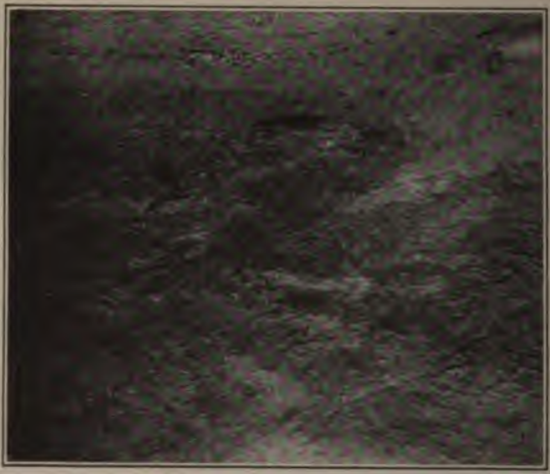


FIG. 16.
Local folding in the jasper beds exposed at Golden Gate Park.

are besides these two small synclines, one of which is exposed at Lombard and Larkin streets, the other on Jones street near Vallejo street.

There are other minor lines of faulting but they are not of enough importance to be mentioned here.

A noticeable feature of the sandstone of the city is their jointing. These joint planes cut the rocks in many directions, without any apparent regularity, giving in exposed places such sharp, pro-

Fig. 17.

Serpentine of the Presidio sill resting upon a sandstone floor.

jecting, triangular faces, as to make it difficult or impossible to distinguish the original bedding planes. The pressure that produced these results in sandstone has not broken the jasper but merely thrown it into complicated folds.

Structure of Serpentine Intrusions.—All the serpentine areas of San Francisco peninsula are in the form of sills. The largest of these is the Presidio, and next are two nearly as large at the Potrero and at Hunter's Point. In the last two areas the hypersthene diabases have been intruded and have been broken up by the movements within the serpentine itself, during the process of hydration.

As a result of this breaking up the diabase outcrops are irregularly scattered through the serpentine areas. The sills at the Presidio and Potrero show the presence of two different serpentine intru-

Fig. 18.

A place in the cliffs north of the Presidio where the serpentine is intruded into the shales of the Telegraph Hill beds.

sions; whether they both occurred at the same time or at different times is not clear.

Sections through these different sills show their structural features plainly.

V. Physiography.

The main features of the topography of the northern end of the peninsula are controlled by the major faults, giving as a result two large blocks tilted toward the northeast, and one block with complex folding. The northwest-southeast trend of Buri-Buri ridge, San Bruno Mountain and the line of jasper hills across the city from the Cliff House to Hunter's Point is characteristic of the Coast Range ridges that are determined by major and minor faults and major folds. These features are plainly shown in the accompanying photograph of a relief map of the peninsula made by A. H. Purdue, of Stanford University.

Fig. 19.

Relief Map of San Francisco Peninsula by A. H. Purdue, 1894.

Merced Block.—Without considering the region south of San Andreas Lake in the Merced series, there is a tilted block, with terraces both older and newer than the faulting. This may be regarded as one large block that has many minor faults or smaller blocks of the same type as the large one. The largest of these faults, the one at Wood's Gulch, has determined the stream drainage at that point. Otherwise the drainage of the whole block is toward the northeast, or down the slope of the tilt. These streams have their heads in circular canyons, and which must represent a drainage system older than the Merced formation. The Franciscan series, forming the northeast front of the Buri-Buri ridge, are the cliffs of the pre-Pliocene beach, and the fact that the Merced series rests on the tops of these hills with almost a flat area shows that

FIG. 20.

A typical form of topography in the beds of the Merced series.

this is a pre-Pliocene terrace. The presence of the Merced series in place in the creeks and between hills of Franciscan sandstone indicates that the present drainage is controlled by the older drainage, the existing streams running down the submerged valleys of pre-Pliocene times.

Drainage.—The long, low valley between Buri-Buri ridge and San Bruno ridge is a slight syncline, the form of which is determined by the thrust block on the southwest side. It may have been the formation of this syncline that has controlled the drainage of the stream that once flowed through the basin now occupied by Lake Merced. This lake has been formed by the damming of the stream's mouth by a barrier beach; the bottom of the lake is now about ten feet below sea level.

San Bruno Block.—The physiography of the San Bruno block is apparently older than that of the Merced block and is determined mainly by structure.

Effect of Structure.—The next feature of note is the San Bruno thrust block. Along the southwestern side of the San Bruno range is a ridge of low hills capped with jasper. In the geological column these are probably within a few hundred feet vertically of the jaspers represented on Buri-Buri ridge. As these jaspers dip toward the southwest while those on Buri-Buri ridge (except near the fault zone) appear to dip toward the northeast there is the suggestion of a pre-Pliocene syncline, whose eroded trough has been the place of deposition of the Merced series. If the San Bruno fault is pre-Pliocene, as it seems to be, then the valley in which the Merced was deposited was an eroded syncline between fault blocks. The greater age of the San Bruno fault is shown by the more mature topography of that range as compared with the Buri-Buri country.

With one exception the streams of the San Bruno block drain northeast or southwest. In this exceptional case the stream turns at a right angle from a northeast direction and flows southwestward along the northeast side of the San Bruno mountains in a direct line with the Guadalupe Valley. The direction taken by this stream lends color to the suggestion that the Guadalupe Valley is a minor fault valley like Visitation Valley.

Drainage.—The anticline in the southwest edge of the San Bruno mountains shows its effect upon the topography at Ocean View where it has broken down. Heading near Ocean View is Islais Creek which runs by an indirect line to empty into the bay south of the Potrero. The drainage of this stream must have been guided by some previous topographic features that are not now

evident, though it follows the general northeast trend of the other streams. It is at present slowly filling the basin between the Potrero and Hunter's Point.

The hills through the center of San Francisco, at Golden Gate Cemetery, Strawberry Hill, San Miguel Hills, Bernal Heights and University Mound, owe their prominence to the large beds of jaspers that compose the major part of them. This jasper does not weather like a sandstone, but only breaks down slowly by mechanical means. The canyon through Almshouse tract, with its feeding streams, and the gap through Twin Peaks and Sunnyside addition are formed by the more rapid disintegration of the Silver Terrace sandstone than of the jaspers. The topography of this area in the heart of the city is controlled partly by the jaspers and serpentines and partly by the structure.

Lone Mountain Block.

Effect of Jaspers.—There is a low divide caused by the Lone Mountain fault crossing San Francisco from a point just northeast of Lobos Creek past Lone Mountain, to Hunter's Point. Parallel to this is a line of hills on which the cemeteries are located and Lone Mountain which have survived erosion because of their synclinal structure and the serpentine areas that have helped resist rapid weathering.

Effect of Serpentines.—The Presidio, Potrero, and Hunter's Point remain as noticeable features not because of the slowness with which serpentine alters, but because of the slowness with which it breaks down and is carried off by erosion. The reason the upper beds of sandstones and jaspers do not remain in places over these sills is because the large amount of movement that has taken place has so broken and crushed the overlying sandstone that erosion has been greatly facilitated.

Two small hills, one at Silver Terrace, and the other one and three quarter miles south of South San Francisco, owe their topographic relief to the intrusion of igneous rocks that have metamorphosed the tufaceous materials present to hard resisting greenstone.

Effect of Structure.—The divide between Lafayette and Russian

hills and Black Point and Russian Hill represents broken down anticlines while that between Russian and Telegraph hills along Montgomery avenue is a synclinal trough.

The flat in the business portion of the city with its sands and mud obscures the structure of the gap between California street hill and Rincon Hill. Rincon Hill being folded in a syncline parallel to the minor lines of folding, has the dip of the beds in a different plane from the dip of California Hill beds. The apparent solution is that Market street has been the direction of drainage of a stream passing between the two hills, through an eroded anticline.

There are no streams now draining this flat but if there were their drainage would be northwest-southeast along the axes of folding and at right angles to the direction of the streams on the tilted blocks.

The series of elevations and depressions to which this area has been subjected have not all left traces upon it. Various places around the bay show an old raised shore line. There are two terraces along Buri-Buri ridge—one at an elevation just a little above the floor of Merced Valley, the other at an elevation of five hundred feet. This last one is the pre-Pliocene terrace previously mentioned.[1]

VI. General Discussion.

Age of the Franciscan Series.—The age of the Franciscan series is not definitely and directly known from paleontological evidence, but must be arrived at indirectly by the age of the superimposed beds. The Franciscan series of sandstones and jaspers is very much broken up, metamorphosed and silicified by the dynamic movements through which it has passed. By this and by its constant macroscopic and petrographic characters it may almost always be recognized.

The conclusions of Dr. Fairbanks and Dr. Becker from their

[1] Lawson, A. C., Geology of the San Francisco peninsula. 15th Ann. Rept. U. S. Geological Survey, p. 464.

G. H. Ashley, Neocene Stratigraphy of Santa Cruz Mountains, Proc. Cal. Acad. Sci., Series 2, V, 354.

A. C. Lawson, Geomorphogeny of the Coast of Northern California, Bull. Dept. Geology University California, I, No. 8, p. 241.

work on the Franciscan series, are, that it is at least pre-Cretaceous in age, but how much older, is as yet unknown.[1]

Formation of the Merced Series.—The mode of formation of the Merced series seems from all the field evidence to have been a local deposition in an arm of the sea, or an outlet to the bay corresponding to the present Golden Gate. In the area south of this are large deposits of fresh water gravels that are considered by Dr. Arnold to be the fresh water equivalent of the Merced series. If this is true and these fresh water gravels represent a fresh water lake which emptied into the Pacific Ocean by way of the Merced outlet, then there should be faunal evidence of the change from fresh to salt water forms. Work of the nature that would demonstrate the plausibility of this theory has never been attempted. There remains, however, the conclusion that this great thickness of Pliocene beds exposed at Seven Mile beach is a local deposit formed in one of the two ways suggested and undoubtedly not extending in any such thickness over the main San Francisco Peninsula.

Origin of the Jaspers.—The Franciscan jasper was considered by Becker as metamorphosed silicious shale,[2] and by Lawson as a deposit from submarine springs.[3] The wide spread extent of the beds shows it to be a true bedded deposit, as it is known to extend from near the Oregon line to Santa Barbara county.

The presence of radiolarian remains in the jasper also show it to be a marine deposit. These fossils do not prove that the jaspers are composed of radiolaria but show that it is similar to present-day deep sea deposits. The agencies that have metamorphosed the sandstones have probably helped in the secondary silicification of the jaspers.

There is another possible origin for the large beds of jaspers in the Franciscan series and this is suggested by similar beds in later deposits. The siliceous Miocene shales resemble very closely the jasper beds under discussion except that they do not show so much folding and distortion. These Miocene shales are diatomaceous

[1] The Pre-Cretaceous Age of the Metamorphic Rocks of the California Coast Ranges, American Geologist, IX, 153. Monograph XIII, U. S. Geological Survey, p. 211.

[2] Monograph XIII, U. S. Geological Survey, p. 106.

[3] A. C. Lawson, 15th Ann. Report U. S. Geological Survey, p. 440.

deep sea deposits, altered since the time of their deposition. It is reasonable to assume that the older jasper beds may have been formed similarly to those of the Miocene age whose origin is known.

The fact that remains of diatoms do not show in slides of the jaspers does not prove that they were not there originally. These jaspers are mostly amorphous silica and must have passed through a stage of solution and re-deposition from their original form so that all traces of diatoms might easily be lost.

This hypothesis is worthy of consideration because of the large deposits of siliceous shale that we have in California; and it is more reasonable to consider the older jaspers formed after the same method of later shales, than to assume a different set of conditions and different organisms to have existed without any definite proof. The presence of radiolaria does not affect this either way because small amounts of any organism might be present with the diatoms and have their skeletons preserved.

The fact that in San Francisco we have a lignite and tuffs interbedded with the jaspers is significant. This lignite and tuff show conditions different from those under which the jaspers were deposited. The jaspers represent deep sea or at least quiet water conditions. The presence of lignite shows land conditions, while the jasper pebbles in the sandstone show that the Franciscan area was above the sea and that erosion had set in.

The tuffs present may mean that a period of volcanic activity was the cause of the change in the conditions under which the jaspers were being deposited and a return to land conditions as shown by the lignites. In this same sandstone are large and small pieces of shale, that resemble the shale of the series of rocks underlying the jaspers. This suggests that erosion went through the entire jasper bed and well down into the San Bruno series. There must be somewhere then, an unconformity in the series itself. The extent of this erosion interval is not known nor its place except that one area out of water must have been near the present city, as the pebbles are large and subangular. The second large bed of jasper shows the return of conditions favorable for the deposition of jasper.

Work through the area south of San Andreas lake and over the Santa Cruz quadrangle shows that the jaspers have been removed

from the southwest side of the San Andreas-Stevens Creek fault line but that remnants are still preserved on the northeast side. There is the possibility that the first movement along this fault line occurred at the time represented by the unconformity shown by the pebbles in the Silver Terrace sandstone. The area containing the unconformity is on the southeast side of this fault line, but the removal of the jaspers may be due to the erosion of the hills southwest of the fault during Pliocene times.

After the deposition of the jaspers conditions changed and the sandstones were deposited that appear in the northern end of the peninsula. The writer feels fairly sure that he has seen this Silver Terrace sandstone in other localities with the jaspers. Dr. Becker asserts that the granites underlie the Franciscan Coast Ranges. Then if this uplift took place, as suggested during the period of deposition of Silver Terrace sandstone the erosion would be greater in the Santa Cruz mountains on the southwest side of the San Andreas-Stevens Creek fault and would account for the appearance of the Montara and Ben Lomond granites.

Besides the large areas of jasper, there are small areas in various places throughout the Coast Ranges that do not seem to belong to the main beds. These may possibly be erosion remnants left by the removal of the larger masses, or it may be that the organisms forming the jaspers survive in colonies that form small lens-shaped masses. This latter suggestion receives support by evidence found at a place in the cliffs near Golden Gate Strait, where about six or eight inches of jasper appears in the sandstone several feet below the bottom jasper beds. The small bed appears to show the arrival of the first condition that allowed the development of the organisms followed by a period of slight change with sandstone and final settling to the quiet conditions in which the larger deposits were laid down.

The writer is of the opinion that both of these conditions may be found in any area where the jaspers occur.

Origin of the Serpentines.—The field evidence in San Francisco shows that the serpentines are formed by the alteration of olivine and pyroxene-bearing rocks. The large number of exposures has allowed the collection of an abundance of fresh specimens of the

rock. In the first part of the paper the petrography of these serpentines was given. There can be little doubt but that the serpentines elsewhere in California are of the same origin as these in this area; that is an alteration from olivine and pyroxene-bearing rock. Field observations at New Idria quicksilver mine and other places confirm this opinion.

The age of the serpentine intrusions on the San Francisco peninsula is not determinable, but field evidence elsewhere shows their age to be post-Knoxville and pre-Chico. In his work in the Coast Ranges Dr. Becker reports finding serpentine boulders in the bottom of the Chico,[1] which makes them pre-Chico. Dr. Fairbanks reports that on Grindstone Creek, Colusa county, the Knoxville shales have been metamorphosed for some distance by the intruded serpentine making the age post-Knoxville.[2] He also thinks that the unconformity between Knoxville and Chico may be due, in part, to the movements caused by the intrusion of these peridotite masses.

Origin of the Schists.—Whether the schists of the Coast Ranges are due to contact or regional metamorphism is a question that is still open. There is no evidence in the schists of the peninsula to prove this point definitely one way or the other. The schists occur both with and away from the serpentines. The quartzose glaucophane schist, described earlier in the paper, seems a result of dynamic rather than of contact metamorphism.

In connection with the formation of schists from contact with serpentines it may be said that the fact that sandstone taken from contact with the serpentine shows no noticeable metamorphism indicating that the action of the serpentine is not very great. If the schists were formed by regional metamorphism they might be formed along lines which would then be the places where the serpentines could be most easily intruded.

VII. The Earthquake of April 18, 1906.

Since the preparation of this paper there has occurred in California, and especially in this district, a seismic disturbance of unusual violence, resulting in the destruction of much property and a

[1] Monograph XIII, U. S. Geological Survey, p. 186.
[2] Fairbanks, American Geologist, IX, p. 161.

small loss of life. Inasmuch as this area is directly affected, a few remarks, of a general nature, are appended regarding the relations of the general geologic structure to the earthquake.

Relations to Structure.—As shown in the chapter on structure the northern end of the peninsula has its main features determined by three faults. The largest of these is the San Andreas-Portola fault which is one of the main lines of weakness in the Coast Ranges. The earthquake is supposed to have been caused by the movement along this old fault line. This disturbance was felt violently from Eureka, in northern California, to southern San Benito county. This is along the northwest-southeast line of valleys, continuous with Santa Clara Valley. Parallel to the fault zone the many towns in these valleys seem to have felt the earthquake with approximately equal intensities. Crossing the fault zone, at right angles, in a northeast direction, there seems some slight movement along a parallel line of weakness passing down through San Francisco Bay by Alviso, and southeastward, but there is no plain proof of this movement. The intensity decreases rapidly, going eastward from the fault, toward the San Joaquin Valley.

Movement along the San Andreas-Portola Fault.—The movement along the San Andreas-Portola fault line is quite apparent and consists of a thrust of the Merced block from three to eight feet toward the southeast, along the direction of the fault, with a slight downthrow, perhaps an average of twelve inches on the southwest, the first movement being the more important.

Intensity.—In San Francisco the general intensity was slightly less than that in some of the smaller towns near by. Substantial structures in that city were only slightly injured, broken chimneys and small cracks being the usual destruction. A considerable number of old and poorly made buildings fell with a slight loss of life compared with the population of San Francisco. The small number of deaths, however, was due to the hour at which it occurred. Disastrous fires broke out immediately and caused loss of life much larger than would have resulted from the earthquake, and with a loss of property that was excessively large in proportion to the damage done by the earthquake.

Effect.—In certain localities, between Lafayette Hill and the

cemeteries, on the north side of Russian Hill, in the district south of Market and in Mission valley near Eighteenth street, the intensity seems to have been greater than in other places through the city. Houses were completely demolished, car tracks twisted and broken, and water pipes bent.

Relations to Soil and Rocks.—In the first two districts mentioned the damage is due to the settling and sliding of sand on the hillsides. This is best shown near Steiner and Union streets, where crescent-shaped cracks appear in the street. In one place a house set on the hillside moved forward, down hill onto the sidewalk.

FIG. 21.

Union street near Steiner, showing the effect of a landslide caused by the earthquake.

In the other areas the buildings damaged stood mainly upon filled ground or recently formed loosely set soil. On Valencia street, where the greatest damage was done, a hotel that sank into the ground was upon material that had filled an old creek channel. The area directly around was also intensely disturbed, due, perhaps,

to the loosening of the soil by the circulation of waters made necessary by the filling of the old stream channel. The area on Howard street shows merely what happens when houses are on a landslide, as this is nothing more or less than a small, low angle landslide. These low angle slides are common in the soft Merced beds and at one place, near Mt. Olivet Cemetery, the soft wet æolian sand flowed several hundred yards down hill at a low angle, damaging the power house and carrying a lumber pile along with it. It is evident that the places that suffered most were those that stood upon loose sands or soils.

Other districts on the Franciscan rocks did not suffer so much and two areas especially, the Potrero and the Presidio, though offering no large buildings for comparison, seem to have suffered least. It is supposed that the reason for this is that the serpentine, with its many slickensided faces, has taken up a large part of the movement.

Along the San Andreas-Portola fault line the fissure formed by the movement may be seen plainly until it reaches the serpentine of Las Pulgas sill, where it almost disappears, but reappears plainly upon the southeast side of the serpentine. This fault line along which the movement took place in causing the earthquake may be plainly traced from Mussel Rock to Spring Valley lakes at Crystal Springs and on toward the southeast. It has the appearance of an irregular plowed furrow with occasional side furrows. The general downthrow cannot be observed continuously and persistently, but occasionally local variations of even as much as four or five feet occur, crevices being opened from a few inches to a few feet in one spot. The lateral thrust is not always apparent on the ground, but it may be clearly seen in the broken and offset fences across the fault. Various measurements of the slippage gave an average of three feet, but as much as eight and a half feet has been found near Woodside, San Mateo County.

Movements Along the San Bruno and Lone Mountain Faults.—The other two fault zones of the San Francisco peninsula, the Lone Mountain and San Bruno faults, show no discernible movement, and the intensity in the city of San Francisco shows no relation to these or any other structural features. In the area mapped the part that seems to have suffered most is in the soft Merced beds

near Baden. The cemeteries just north of that place show considerable evidence of the intensity of the shock. Holy Cross Cemetery suffered most, as much as seventy per cent. of the monuments having been overthrown, while many others turned or slid upon

FIG. 22.

A bend in the tracks of the South San Francisco car line near Baden.

their bases. Most of the monuments overthrown fell in a northwest or southeast direction and those that were twisted moved toward the southeast. All have not fallen in these directions, however, for the remaining fallen monuments lay in almost every possible direction.

Local differences in intensity are common and are shown, for example, by the fact that without any apparent reason Cypress Lawn had but a slight loss in comparison with Holy Cross Cemetery, which adjoins it, and which has the same soil.

At South San Francisco, several miles east of Baden, the movement does not show the same intensity as is seen in the Merced Valley. This is especially noticeable from the fact that the six or seven

brick chimneys were not thrown down, though some of them were cracked. These are within a very short distance of the San Bruno fault zone, and had there been any movement along that fault the intensity at South San Francisco would have been much greater.

The beds of the Merced series near and north of Mussel Rock are cracked, fissured and faulted in every direction. The Pliocene section along Seven Mile beach has been so altered by landslides

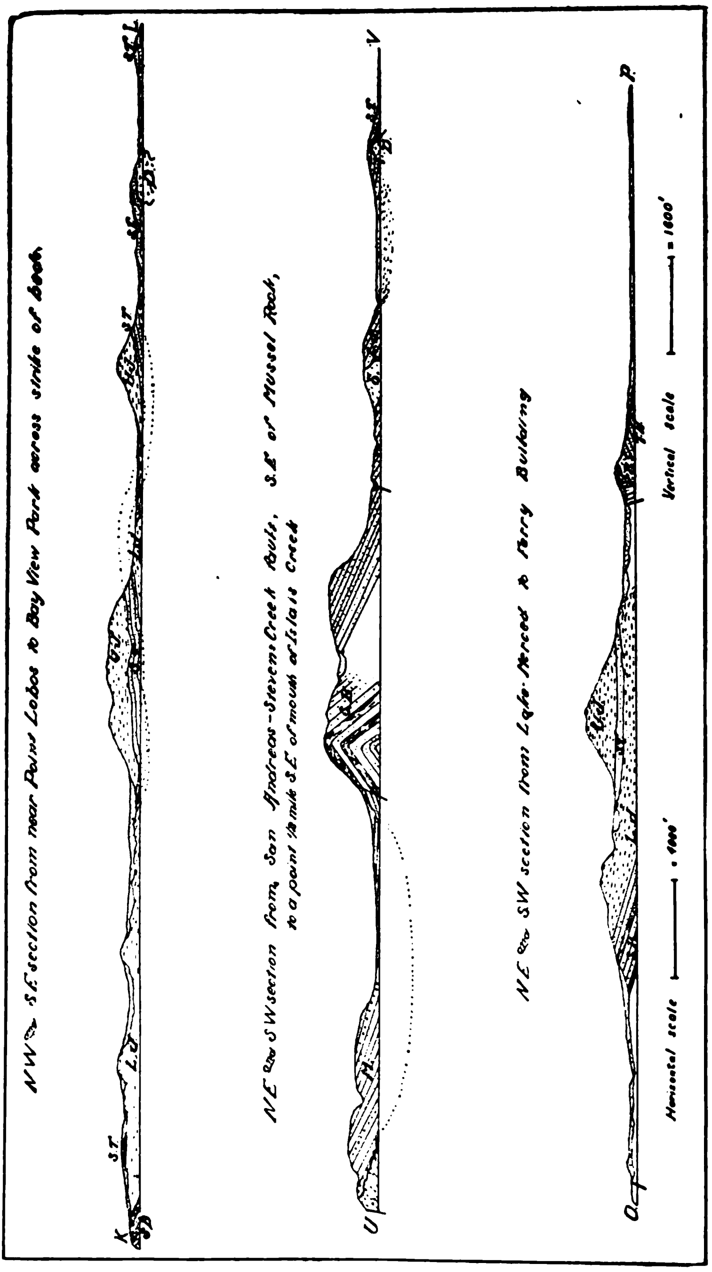
FIG. 23.

Effect of the earthquake along the road bed of the Ocean Shore Railway; three miles north of Mussel Rock.

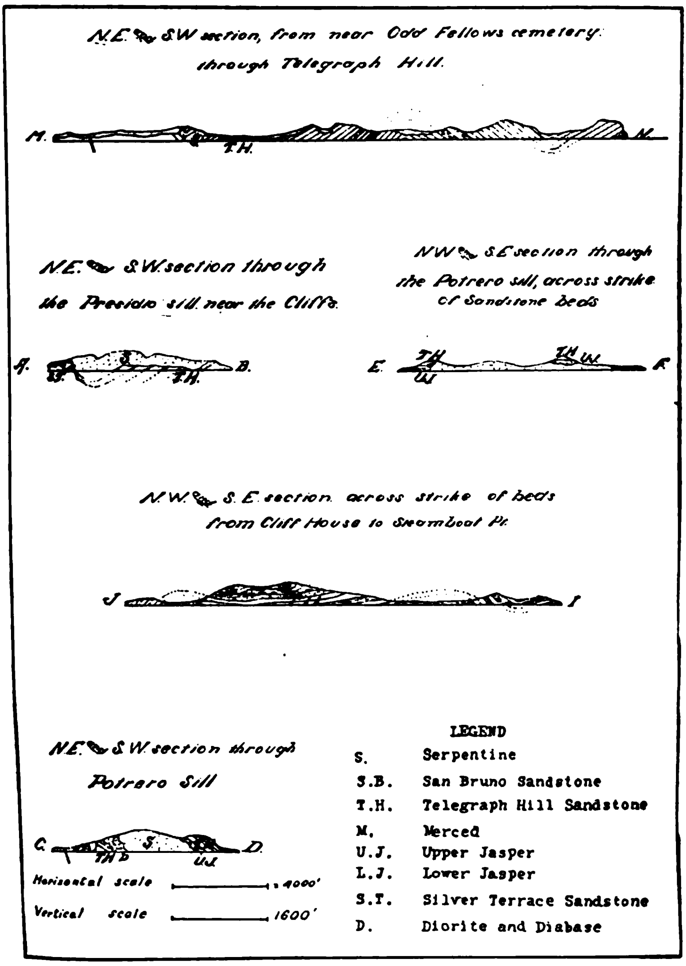
that it is hardly to be recognized. There is a tendency here for everything to slide into the ocean, even as far as four or five hundred feet from the cliff's edge. The road bed of the Ocean Shore electric railway line was seriously damaged along this bluff. Through Wood's Gulch and southeast of there along the fault line, landslides occur on both sides of the canyon, and long cracks cut across the hills just above the Chinese cemetery, showing that this fault is directly related to the main fault and probably formed at

the same time. The cracks in the hills southwest of the Chinese cemetery are almost in a direct line with the fault and may indicate a slight movement. The fact that these cracks are not continuous, so that they may be easily traced through Wood's Gulch to the ocean, leads to the belief that they are merely due to the settling or to the beginning of large landslides on the hill tops.

Movements of the adjoining Blocks.—The southwest side of the main fault line seems to be almost entirely free from cracks and fissures, though there are many and large landslides. The general evidence is that the intensity on this southwest side of the fissure zone was about the same as it was on the northeast side.



Sections of San Francisco Peninsula.



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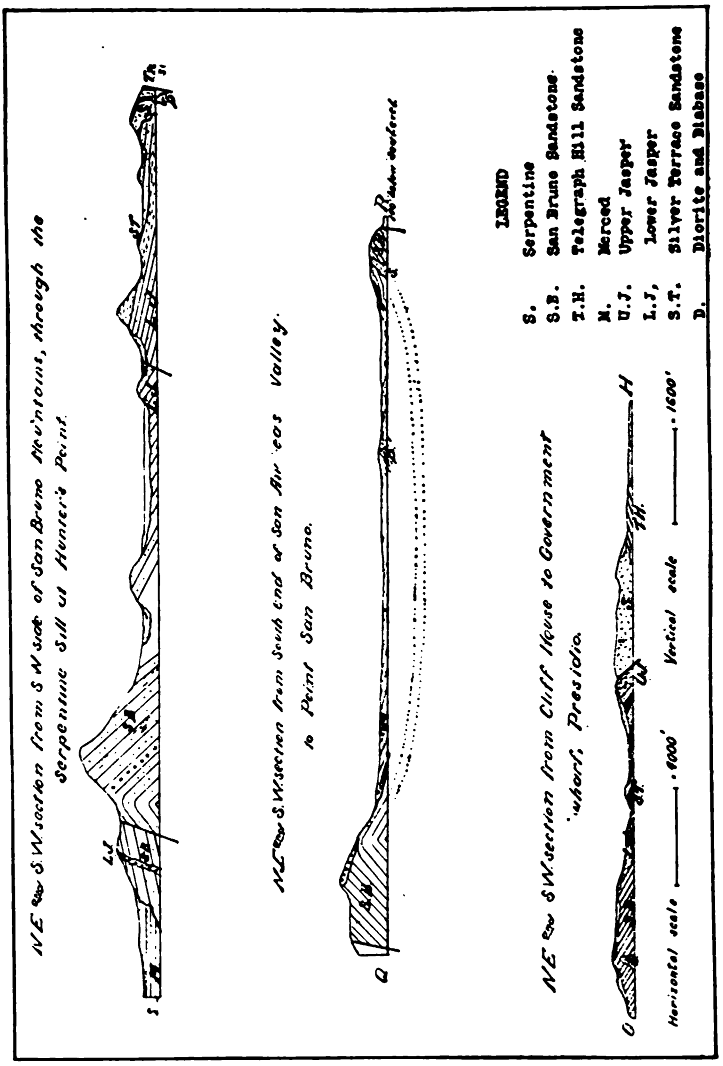


Sections of San Francisco Peninsula.

THE CATHODIC PRECIPITATION OF CARBON.

By WILLIAM BLUM and EDGAR F. SMITH.

(Read January 4, 1907.)

(Contribution from the John Harrison Laboratory of Chemistry.)

Some years ago[1] one of us (S) called attention to the electrolytic precipitation of iron, by the current, from citrate and tartrate solutions. In doing so, mention was made that on dissolving the deposited metal "in dilute, cold sulphuric acid a strong odor of hydrocarbons was perceptible." Later,[2] reference was again made to this fact and conditions given, observing which, the contamination of the metal by carbon might be avoided. In electro-analysis, the question of the contamination of metals by carbon, if the metals have been precipitated from organic electrolytes, has been quite freely discussed. However, the contamination in nearly all instances has been regarded as a result of carelessness in manipulation and may be avoided.

During the past summer we made observations, on the conduct of certain organic acids under the influence of the current, which seem of value, hence a brief account of them is submitted in this communication.

To begin, it was tried to ascertain the degree of reduction of oxalic acid at the cathode. The gasometric method was called into use, *e. g.*, a comparison of the volume of hydrogen evolved in the cell, with that liberated in a voltameter in the same period. It soon became evident that this procedure would not be delicate enough to detect any such reduction. However, while occupied in this way with an ammoniacal tartrate solution, a black deposit made its appearance on the cathode. When held in the flame it burned off completely from the platinum plate. The latter had an area of 100 sq. cm. Several actual trials may be here introduced. Thirty-seven

[1] *Am. Chem. Jr.*, 10, 330 and *Jr. Analyt. and Applied Chemistry*, 5, 488.
[2] Smith's "Electrochemical Analysis," 3d edition, p. 100.

and one-half grams of tartaric acid were dissolved in water, neutralized one-half with ammonia, then diluted to a liter. Portions of this solution were electrolyzed at a temperature of 60° C. The anode was a platinum spiral suspended in a porous cup. The cathode was the foil to which reference has been made. A current of one ampere and twelve and one-half volts acted for a period of two hours. A black deposit showed itself on the cathode. It burned off in the flame. In another experiment, with conditions like those just mentioned, discarding, however, the cup, there was no deposit on the cathode, but the solution was deep yellow in color. Again, in electrolyzing a portion of the ammonium tartrate without the porous cup, but surrounding the anode with a muslin bag, at the ordinary temperature, with a current of 4 amperes and 6 volts, there was a very considerable deposit, black in color, on the cathode. It burned away, with the exception of a mere iridescence, when held in a flame. In another experiment, fifteen grams of tartaric acid were neutralized with ammonia, diluted to 150 c.c. and electrolyzed at 60° C., for four hours, with a current of 4 amperes and 6 volts. The anode and cathode had both been weighed. The cathode became coated with a grayish black deposit. The anode sustained a loss in weight and only one-third of the cathodic deposit was carbon, the remainder being platinum, which had come from the anode.

Upon substituting a solution of citric acid (70 grams to the liter) and electrolyzing at 70° C., for three hours, with a current of one ampere and sixteen volts, a heavy black deposit separated on the cathode. It was not affected by hydrochloric acid. It burned away completely in a Bunsen flame. The electrodes were separated by a porous cup. In other experiments a muslin bag surrounded the anode. This bag had previously been well soaked in caustic soda. The usual black cathodic deposit was obtained. It burned away completely on heating. On digesting this deposit with chromic acid, carbon dioxide was obtained and recognized by its reaction with lime water.

Another trial is worthy of notice. In it a half normal solution of ammonium citrate, made alkaline with ammonia, was electrolyzed for a period of five hours with a current of 4 amperes and 6 volts. The anode was protected by a muslin bag. The solution

rapidly took on a yellow color, a distinct odor of acetamide was evolved and a black deposit appeared upon the cathode. It both burned on heating and generated carbon dioxide with a chromic acid mixture. It may be added that the solution was not heated from without as it developed a great deal of heat during the passage of the current.

Similar results were obtained on electrolyzing a like solution with out a diaphragm.

Other experiments were as follows:

1. Five grams of sodium citrate and one gram of citric acid were dissolved in 150 c.c. of water and electrolyzed at 60° C., for five hours, with a current of 4 amperes and 11 volts. There was a brass-like deposit on the cathode. It weighed 0.0018 gram, while the anode had lost 0.0014 gram.

2. Fifteen grams of citric acid, neutralized with ammonia and diluted to 150 c.c., were electrolyzed at 60° C., for four hours, with a current of 4 amperes and 6 volts. A grayish black deposit separated on the cathode. It equaled 0.0014 gram, which represents carbon. The anode lost in all 0.0103 gram in weight.

In the many trials made, the solutions gradually acquired first a pale yellow color which in turn passed to brown and at times almost black without becoming turbid. However, it must be said that solutions of ammonium oxalate, ammonium formate, ammonium acetate and ammonium succinate did not yield black deposits to the cathode. In solutions of ammonium lactate and benzoate they appeared as readily as in tartrate and citrate solutions.

This deposition of carbon upon the cathode is extremely interesting. In 1896, Coehn (*Z. f. Elektrochemie* (1896), p. 541) called attention to the fact that when carbon was made an anode in the electrolysis of sulphuric acid, the latter became at first yellow, and by prolonging the experiment, dark red and reddish brown in color. If this meant a solution of carbon the latter must presumably be in the form of ions, *e. g.*, in a form directable by the current. It must be in a form, which, as it does not decompose water, would appear at the anode. With these thoughts before him, Coehn electrolyzed sulphuric acid of varying concentration with an anode of carbon and a cathode of platinum. The result was a splendid deposition of carbon on the cathode. It burned away completely on

heating and gave carbon dioxide when acted upon with a chromic acid mixture. In later experiments, Coehn was able to determine, in the electrolytic way, the equivalent of carbon and found it to be 3.

Turning to our observations with tartaric and citric acid, it must be that these are broken down at the anode, during electrolysis; that the carbon thus liberated from combination in these acids enters aqueous solution as a hydrate of which the carbon is cation, and this, under influence of the current, passes in its ionic form to the cathode just as a metal, in some salt, does under similar influence. When, therefore, iron is deposited from a citrate or tartrate electrolyte, the carbon ions wander with the iron ions to the cathode, and there an alloy of iron and carbon appears. This alloy, on treatment with dilute sulphuric acid, generates hydrocarbons. Very little, if any, of the carbon deposited with iron is graphitic. It is chemically combined. Just as zinc and copper, from certain electrolytes, separate as brass, so do the carbon and iron separate as an alloy from the electrolytes which have been under discussion.

The conclusions warranted from the experiments here noticed and many others like them are:

1. Carbon is deposited on the cathode from solutions containing tartaric, citric, lactic and benzoic acids. This is particularly the case if a stationary anode be used along with high current density.

2. From solutions like those in 1, where high current density is employed, platinum will dissolve from the anode and be precipitated in part upon the cathode.

UNIVERSITY OF PENNSYLVANIA.

Stated Meeting January 18, 1907.

President SMITH in the Chair.

The following papers were read:

"Pennsylvania at the Jamestown Exposition, illustrated by the Lincoln Migration," by PROF. MARION D. LEARNED, which was discussed by Mr. Richard Wood, Prof. Cheyney and Prof. Leslie W. Miller.

"Reproduction, Animal Life Cycles and the Biological Unit," by PROF. THOMAS H. MONTGOMERY.

Stated Meeting February 1, 1907.

President SMITH in the Chair.

The decease was announced of Sir Michael Foster, F.R.S., on January 29, 1907, æt. 71.

PROF. EDWARD P. CHEYNEY read a paper on "The Roman Wall in Britain."

Stated Meeting February 15, 1907.

President SMITH in the Chair.

The following invitations were received:

From the Chicago Historical Society inviting this Society to be represented at the commemoration of the fiftieth anniversary of its incorporation on February 7, 1907, and Prof. A. A. Michelson was appointed as the Society's delegate on the occasion.

From the Seventh International Zoölogical Congress inviting the Society to be represented at the Congress to be held in Boston on August 19–23, 1907.

From the University of Upsala inviting the Society to be represented at the celebration of the two hundredth anniversary of the birth of Carolus Linnaeus on May 22d and 23d next. Dr. William W. Keen was appointed to represent the Society at this celebration.

The following communications were received:

From the Chancellor of the Smithsonian Institution announcing the appointment of Dr. Charles D. Walcott as Secretary of the Institution to succeed the late Samuel Pierpont Langley, deceased.

From the University of Aberdeen acknowledging the Society's congratulatory address on the occasion of its Quatercentenary.

From Mr. John H. Harjes, of Paris, presenting two large bronze plaques, and on motion the following minute was unanimously adopted:

Mr. John H. Harjes, with great and generous kindness, has presented to the Philosophical Society two *bas reliefs* commemorative of historic incidents in the life of Benjamin Franklin. One represents his reception by the King of France, the other commemorates the signing of the Treaty of Paris. Both are originals, of

which copies are upon the pediment of the statue of Franklin recently presented by Mr. Harjes to the City of Paris.

In accepting these beautiful examples of a difficult art, this Society returns its heartiest thanks to Mr. Harjes for his thoughtful generosity, and assures him of its thorough appreciation of the manner in which he has enriched France and America with appropriate gifts. Such acts of liberal patriotism promote mutual sympathy and amity among nations.

The American Philosophical Society will prize these gifts as enduring ornaments and choice possessions, and upon its walls they shall forever tell their story of the beneficent labors and unending fame of its illustrious founder.

The decease was announced of Prof. Dmitri Ivanovitch Mendeleef at St. Petersburg on February 2, 1907, æt. 73.

Dr. David L. Edsall read a paper on "Occupational Poisoning," which was discussed by Profs. Goodspeed and Smyth, Mr. Goodwin, Dr. Keller and others.

Stated Meeting March 1, 1907.

President Smith in the Chair.

Letter of acceptance of membership was received from Prof. August Weismann.

An invitation was received from the Board of Control of the Michigan Agricultural College inviting this Society to be represented at the celebration of the fiftieth anniversary of the institution on May 28–31 next, at Lansing, and Dr. William Powell Wilson was appointed to represent the Society thereat.

Dr. Allen J. Smith presented a paper on "The Mosquitoes as Bearers of Diseases," which was discussed by Doctors Cleemann, Harshberger, A. E. Brown and Conklin.

Stated Meeting March 15, 1907.

President Smith in the Chair.

The decease was announced of C. Percy La Roche, M.D., at Rome, on March 12, æt. 73.

Dr. Lightner Witmer read a paper on "Clinical Psychology," which was discussed by Mr. Owen Wister, Prof. Conklin, Dr. Frazer and Mr. Witmer.

Stated Meeting April 5, 1907.

President Smith in the Chair.

Invitations were received:

From the Royal Academy of Sciences of Sweden inviting this Society to be represented at its celebration of the 200th anniversary of the birth of Carolus Linnæus, at Stockholm on May 25, 1907.

From the Trustees of the United Engineering Society inviting the Society to be represented at the Dedication of the Building in New York given by Mr. Andrew Carnegie as a home for American Engineering Societies, on April 16th and 17th next.

These invitations were accepted and the President was requested to appoint delegates accordingly.

The decease of the following members was announced:

Albert S. Gatschet, Ph.D., at Washington on March 16, 1907, æt. 74.

Marcelin Pierre-Eugène Berthelot, D. ès Sc. at Paris, March 18, 1907, æt. 80.

John H. Brinton, M.D., at Philadelphia on March 18, 1907, æt. 74.

Dr. Martin G. Brumbaugh read a paper on the "Scope and Possibilities of a Municipal School System" which was discussed by Professors Houston, Miller, Haupt and Snyder.

General Meeting April 18, 19, 20, 1907.

April 18. Afternoon Session.

President Smith in the Chair.

The President opened the meeting with a brief address of welcome.

The following papers were read:

"Analogies Between the colonization of Ireland and Virginia,"

by Prof. E. P. Cheyney, of Philadelphia, which was discussed by Prof. Hewett and Prof. Cheyney.

"Early French Members of The American Philosophical Society," by Dr. J. G. Rosengarten, which was discussed by Prof. Smyth.

"The Influence of Imperceptible Shadows on the Judgment of Distance," by Prof. Edward B. Titchener.

"The Narrative of the 'Walking on the Sea,'" by Prof. William A. Lamberton, which was discussed by Prof. Hewett and Prof. Lamberton.

April 19. Morning Session.

President Smith in the Chair.

The following papers were read:

"Provisional Report of the Investigation of Foreign and Domestic Stage Micrometers," by Prof. Marshall D. Ewell.

"Chauvin (Chauvinisme-Calvin, Cauvin): Truth and Fiction in the Story of its Origin," by Prof. A. Marshall Elliott, which was discussed by Professors E. S. Morse, Jastrow and Hewett.

"Charts Illustrating the Taxonomic Relations of the Monocotyledonous and Dicotyledonous Plant Families," by Prof. John W. Harshberger, which was discussed by Prof. E. S. Morse and Prof. Kraemer.

"Some Experiments with Plant Nutriments," by Prof. Henry Kraemer, which was discussed by Prof. Houston.

"Elizabethan and Jacobian College Dramas," by Prof. Felix E. Schelling.

"The Bacteriology of Flax Retting," by George T. Moore, Ph.D.

"Note as to the Measurement of the Action of Water upon Zinc and Lead," by Prof. William Pitt Mason, which was discussed by Prof. Elihu Thomson, Prof. E. J. Houston, Prof. Kraemer, Dr. Hulett, Mr. Willcox, Dr. Holland and Dr. Mason.

"New Results in Electro-Analysis," by Dr. Edgar F. Smith.

"The Liver as the Seat of the Soul," by Prof. Morris Jastrow, Jr.

Afternoon Session.

Vice-President BARKER in the Chair.

The following papers were read:

"The Progress of the Isthmian Canal," by DR. ELIHU THOMSON, which was discussed by the Right Hon. James Bryce and others.

"The Production of Synthetic Alcohol," by DR. HARVEY W. WILEY and HERMAN SCHREIBER.

"The Princeton Archæological Expedition to Syria," by HOWARD CROSBY BUTLER, which was discussed by Prof. Hewett, Dr. Heilprin and Dr. Butler.

"On the Transportation Crisis," by PROF. LEWIS M. HAUPT.

"The Association Theory of Solutions," by PROF. WILLIAM F. MAGIE.

"The Groups which are Generated by two Operators of Order Two and Four respectively, where Commutator is of order Two," by PROF. G. A. MILLER.

April 20. Morning Session.

Vice-President SCOTT in the Chair.

The following papers were read:

"Santa Cruz Typotheria," by W. J. SINCLAIR.

"The Stercornithes, or Fossil Birds of Patagonia," by MARCUS S. FARR.

"Restorations of Santa Cruz Mammals," by PROF. WILLIAM B. SCOTT, which was discussed by Prof. E. S. Morse.

"Distribution of the Condensation Nuclei in Dustful Air, with Remarks on the Methods of Counting Them," by PROF. CARL BARUS.

"On the Temperature, Secular Cooling and Contraction of the Earth, and on the Theory of Earthquakes held by the Ancients," by DR. T. J. J. SEE.

Executive Session.

President SMITH in the Chair.

The pending nominations for membership were read and the Society proceeded to an election.

Afternoon Session.

President Smith in the Chair.

The tellers of election reported that the following candidates had been elected to membership:

Residents of the United States.

George Ferdinand Becker, Ph.D., Washington.

Charles Benedict Davenport, Ph.D., Cold Spring Harbor, L. I.

J. P. Crozer Griffith, M.D., Philadelphia.

Frank Austin Gooch, Ph.D., New Haven.

Herbert Spencer Jennings, Ph.D., Baltimore.

James Playfair McMurrich, Ann Arbor, Michigan.

Edward Laurens Mark, Ph.D., LL.D., Cambridge, Mass.

John Bassett Moore, LL.D., New York.

Francis Eugene Nipher, St. Louis.

Horace Clark Richards, Ph.D., Philadelphia.

John C. Rolfe, Ph.D., Philadelphia.

Allen J. Smith, M.D., Philadelphia.

Foreign Residents.

Baron d'Estournelles de Constant, Paris.

George Carey Foster, F.R.S., D.Sc., LL.D., Rickmansworth, Herts, England.

J. J. Jusserand, Washington.

John C. Kapteyn, Gröningen, Holland.

Sir William Turner, K.C.B., D.Sc., D.C.L., F.R.S.

The following papers were read:

"On Continental Development," by Bailey Willis, which was discussed by Prof. Scott.

"On Jonah's Whale," by Prof. Paul Haupt.

"A Study of the Mean Temperatures of the Surface of the Moon, Earth, and other Planets," by Prof. Cleveland Abbe.

"Astronomical Photography," by Prof. E. E. Barnard.

"Conservative Systems with Prescribed Trajections," by Prof. E. O. Lovett.

"Comparison of Results of Latitude Observations at the Sayre Observatory, South Bethlehem, and at the Flower Observatory, Philadelphia, from September 30, 1904, to September 3, 1906," by J. H. Ogburn.

"Comparison of Results of Observations at the Flower Observatory for the years 1905 and 1906, with the Wharton Reflex Zenith Tube, and the Zenith Telescope."

"Two Remarkable Double Stars: (*a*) the Short Period Binary, Hough 212, and (*b*), the Stellar System, Krueger 60," by ERIC DOOLITTLE.

ON DISTRIBUTIONS OF NUCLEI IN DUST-FREE WET AIR, AND ON METHODS OF OBSERVATION.[1]

By C. BARUS.

(Read April 20, 1907.)

1. *Nuclei.*—The author remarks that the experiments described all refer to air, from which the ordinary or Aitken nuclei have been removed by filtration. The air is carefully kept saturated with water vapor, and examined in a plug-cock fog chamber by rapid exhaustion, partly without further interference, partly when acted on by the X-rays or the beta and gamma rays or radium, entering the fog chamber from without. The radium was sealed in an aluminium tube. Water nuclei when not themselves the subject of observation (as in § 6) were always scrupulously precipitated.

The kind of nuclei to be considered are thus, first, the vapor nuclei (colloidal nuclei) of dust free wet air, which are probably aggregates of water molecules; second, the ions produced by the presence of the radiant field, natural or artificial; third, water nuclei produced in dust free wet air by the evaporation of fog particles. A careful distinction is here to be made between water nuclei obtained from the evaporation of fog particles precipitated on solutional nuclei, on vapor nuclei, and on ions.

2. *Methods of Observation.*—The number of nuclei was computed from the angular diameter of the coronas of cloudy condensation. These were standardized, as shown in the author's earlier papers, by successive exhaustions, each of the same amount, the residual number of nuclei (after correction for subsidence) decreasing in geometric progression with the number of exhaustions. New experiments were deemed desirable for the present work and were carried out at great length.

To measure the angular diameters of the coronas the older

[1] Extract of certain investigations made by aid of a grant obtained from the Carnegie Institution.

method of a single point of light and a goniometer of special type on opposed sides of the fog chamber was first used. Figs. 2 and 3 give examples of these results.

Subsequently a new method was devised, in which two identical sources of light equidistant from the eye, were moved symmetrically toward and from each other, on a line parallel to the axis of the fog chamber. Observation consisted in placing the fiducial annuli of each of the two coronas in contact, by adjusting the lights at a distance S apart. A lever for this purpose is in the hands of the observer. The normal distance between S and the fog chamber being R and θ the angle of diffraction, $S = 2R \tan \theta$. The advan-

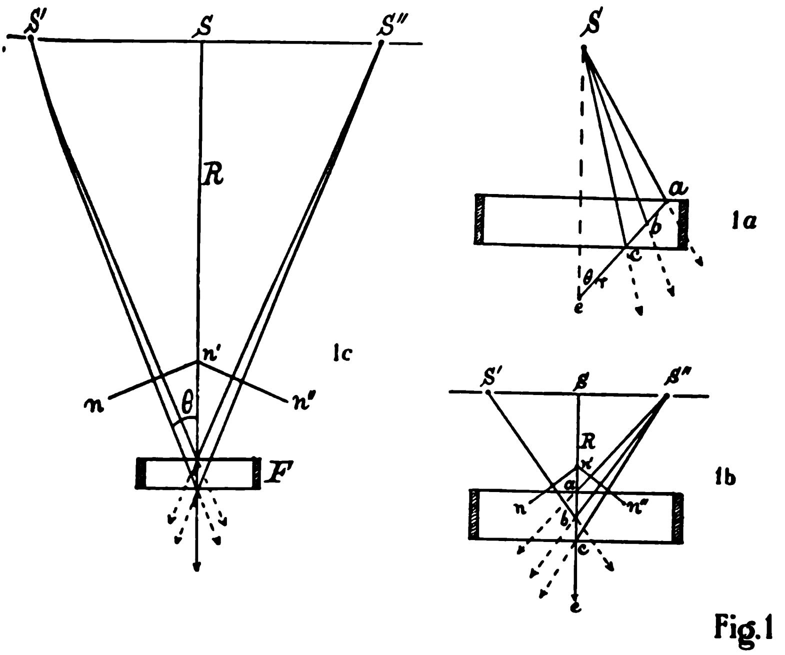


FIG. 1*a*. Diffractions from a single source S from fog particles *a*, *b*, *c*, within the fog chamber, suggesting changes of the angle of diffraction to an eye at *e*. *r* is the radius of the goniometer.

FIG. 1*b*. Diffractions from two sources S' and S'' from fog particles at *a*, *b*, and *c*, within the fog chamber. Coronas nn' and $n'n''$ in contact.

FIG. 1*c*. The same drawn to scale. Fog chamber at F. Angles of diffraction shaded. Coronas nn', $n'n''$.

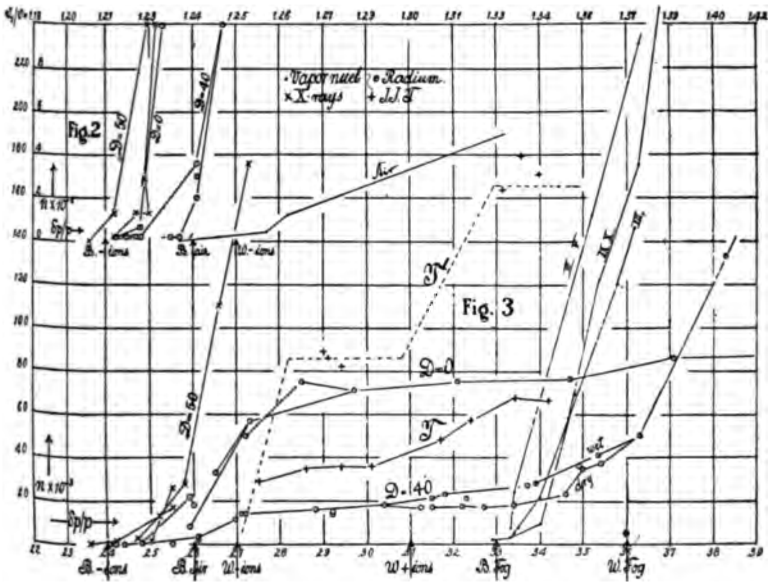
tage of this method of contact consists in this, that the observed diffracton takes place in the equatorial plane of the fog chamber; there is less obliquity of rays, and coronas of any size are observable (an essential condition since the angle for the large coronas approaches 60°), and both eyes may be used, placed all but in contact with the fog chamber. This diminishes the eyestrain and insures sharper vision. Lantern slides were shown giving all the details of this apparatus. The accompanying diagrams 1*a* and 1*b* indicate the differences of the old and new method and the latter is additionally elucidated in figure 1*c*.

3. *The Green Coronas.*—If the coronas be divided into two general types, those which have red discs or red primary annuli, and those in which the discs are green, the latter are convenient for comparison. In successive identical exhaustions they occur at regular intervals and among the larger coronas three successive series are particularly vivid, corresponding to fog particles whose diameters are $d_4 = .00052$, $d_3 = .00040$, $d_2 = .00023$ cm. These numbers may be regarded as in the ratio of 4, 3, and 2, and they suggest a first series with $d_1 = .00013$ as the highest type. The author has not been able to obtain this in any case whatever; but the red type of the first series is well produceable and is the first of a succession of diameters of fog particles, $d_1 = .00016$, $d_2 = .00032$, $d_3 = .00048$, $d_4 = .00064$, etc. The angular diameter of d_1 is about 60° showing the enormous size of the coronas in question. The occurrence of the first series is corroborated by the axial colors of the steam jet.

4. *Wilson's Conclusions as to Size and Number of Fog Particles.*—In the preceding section the conclusion was reached, that the smallest corona-producing fog particles must exceed the order of size, .0001 cm. Mr. C. T. R. Wilson believes that when "all diffraction colors disappear and the fog appears white from all points of view (adiabatic expansion 1.44) . . . the diameter of the drops does not exceed one wave length of light, or 50×10^{-6} cm." What Wilson refered to is probably the filmy disc of the red corona, of the order of $d_1 = .00016$ cm. It is therefore probable that Wilson's final greenish white color corresponded to about 10^6 nuclei, or that the filmy white implies two or three million nuclei, rather than

to 10^8 vapor nuclei per cubic centimeter as he asserts. Compare section 5.

5. *Distribution of Vapor Nuclei and of Ions in Dust-free Air.*— On March second the author gave a resumé of certain typical results to the American Physical Society. Distributions were there given in terms of an unsatisfactory expansion variable, $(\delta p - (\pi - \pi_1))/(p - \pi)$, involving vapor pressure, π, as well as the drop in pressure, δp, from the atmospheric pressure p. In the present graphs these results and the new data specified will be given in terms of the relative adiabatic drop $\delta p/p$, as a more appropriate



Figs. 2 and 3. Distribution of nucleation (n nuclei per cubic cm.) for different drops of pressure δp adiabatically from p, or volume expansion v_1/v. Series III to X were found with dust free air not energised at different times and temperatures. D refers to the distance of the radiant tube or X-ray bulb from the fog chamber. T and T' show the results of J. J. Thomson. W refers to Wilson's fog limits, B to those of the writer. Figure 2 is an enlarged detail of figure 3 refering in particular to the regions of ions.

variable for the plug-cock fog chamber. The adiabatic volume expansion is then

$$(v'_1/v')^\gamma = 1/(1 - \delta p/p),$$

increasing with $\delta p/p$. Numerically $(v_1/v) - 1$ is not very different from $\delta p/p$.

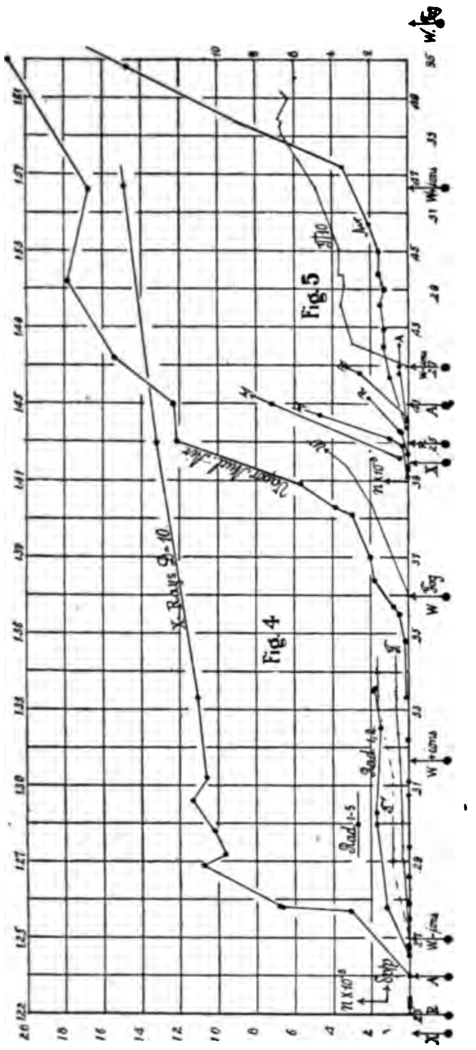
The charts contain an exhibit both of the older results and of new results. In the former the effect of rise of temperature in increasing the available nucleation to the extent of 5–10 per cent. per degree C., is marked. The earlier results are given in Figures 2 and 3.

In the new series (Figs. 4 and 5) and in case of vapor nuclei, the efficiency of the fog chamber breaks down above the green corona at about 1.5×10^6 nuclei per cubic centimeter; $\delta p/p = .41$; $v_1/v = 1.45$. Below this, the graph showing distribution and size of nuclei is well given, ascending definitely from about $\delta p/p = .31$, $v_1/v = 1.30$, which may be called the fog limit. Finally the region of ions appears as a well marked feature of the curve, extending from about $\delta p/p = .31$ to $\delta p/p = .262$, $v_1/v = 1.24$, where condensation begins (negative ions) for vapor nuclei. This is definitely below Wilson's point $v_1/v = 1.25$, for negative ions.

Exposed to the beta and gamma rays of Radium (10,000×, 300 mg.), the limiting ionization observed is below 200,000 nuclei per cubic centimeter; exposed to radium (10,000 ×, 700 mg.), it is below 300,000 nuclei per cubic centimeter; but the condensation begins at $\delta p/p = .26$, or somewhat below $v_1/v = 1.23$, distinctly below the case for dust-free wet air.

The X-rays finally lower this condensation limit still further to $\delta p/p = .247$, or somewhat below $v_1/v = 1.223$, definitely below the point for the weak radium radiation. As compared with the curve for vapor nuclei the steepness of the X-ray curve with strong radiation, its almost sudden ascent is a further feature. It does not however, in my apparatus, get above the large green corona; *i. e.*, about 10^6 nuclei per cubic centimeter are caught at $\delta p/p = .29$, or $v_1/v = 1.27$.

One may notice, therefore, that the plug cock fog chamber puts both condensation points as well as the corresponding distribution of vapor nuclei, definitely *below* the values obtained by Wilson in his piston apparatus (marked *W* in the charts 2 and 3, 4 and 5). Moreover the march of the limits of condensation due to a given



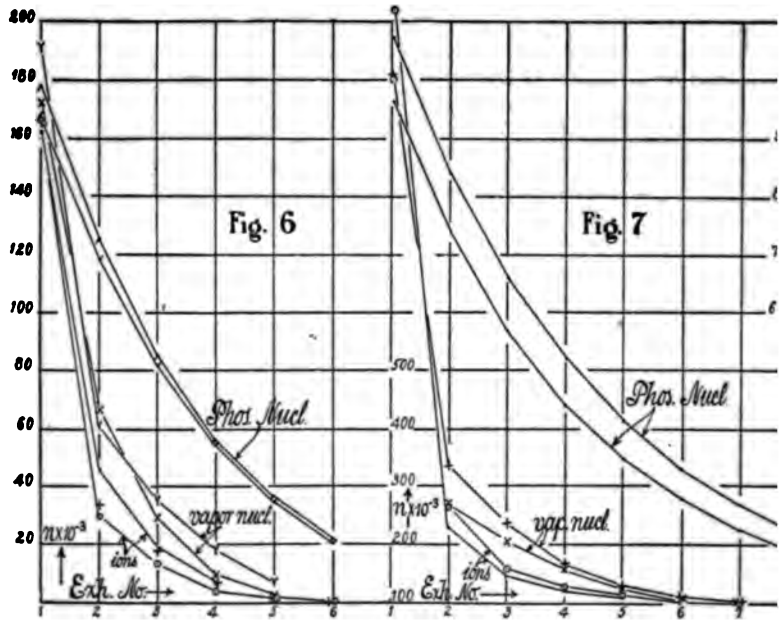
FIGS. 4 and 5. Results essentially like the cases of figures 2 and 3 but obtained by the method of two sources. The scale of nucleation is more compressed (ordinates $n \times 10^{-3}$). X, R, A, show the points at which condensation on ions produced by strong X-rays, by radium, and by natural radiation (dust free air) were observed. W refers to Wilson's results. Figure 5 is an enlargement of figure 4 in the region of ions or for low values of $\delta p/p$. T shows the results of J. J. Thomson.

radiation as compared with a maximum number of ions produc
by that radiation is as follows;

natured radiation, air.........	$v_1/v = 1.24$	$n \times 10^{-3} = 1.5$
Beta and gamma rays used....	$= 1.225$	$= 100 - 150$
X-rays used.................	$= 1.220$	$= 10^5 \ldots 2 \times 10$

Since the intensity of radiation is as the square of the number nuclei, an increase of the intensity of radiation from 1 to 10^4 a from 1 to 10^6 lowers the condensation limit $(v_1/v = 1.24)$, 1.2 and 1.6%, respectively.

6. *Residual Water Nuclei. Behavior on Successive Evapo tion of Fog Particles.*—Water nuclei are obtained by the evapo tion of fog particles, on compression of the dust-free wet air in whi they are suspended. One may expect them to differ with the nucle or ion on which the fog particle is precipitated, and this is the ca



FIGS. 6 and 7. The ordinates show the nucleation (n nuclei per cu cm.) obtained upon successive identical exhaustions and immediate evapo tion, thereafter, of the fog particles precipitated. The abscissas give t number of exhaustions. The ions, the vapor nuclei of dust free air a phosphorus, or solutional nuclei are contrasted. In the latter case, remo by exhaustion is the only source of loss.

The best method of discriminating between water nuclei was found to be the successive evaporation of fog particles precipitated on the same nuclei under identical exhaustions, until the nuclei are wholly removed by the exhaustion and subsidence. The results may be exhibited in graphs, in which for about the same number of initial nuclei, the persistence of the corresponding water nuclei is shown by the number of nuclei which survive after successive evaporations, in case of phosphorus nuclei, vapor nuclei and ions. Compare figures 6 and 7.

In case of phosphorus nuclei, after z identical exhaustions, the number of nuclei n_z remaining is given by

$$n_z = n_1 y^{z-1}\Pi,$$

where n_1 is the initial number of nuclei per cubic centimeter, y the exhaustion ratio and the product, Π, the correction for subsidence; but if ions or vapor nuclei are used, an additional coefficient of loss x must be allotted to each exhaustion, so that

$$n_z = n_1 y^{z-1} x^{z-1}\Pi.$$

The following example shows this clearly.

TABLE I.

Ions.					Water Nuclei.				
z	$n\times10^{-3}$	$n'\times10^{-3}$	x	$(n'-n)/n$	z	$n\times10^{-3}$	$n'\times10^{-3}$	x	$(n'-n)/n$
1	166	166	1.00	0	1	172	172	1.00	0
2	29	117	.25	3.0	2	66	120	.55	.8
3	13	64	.45	3.9	3	29	77	.62	1.7
4	4	25	.53	5.7	4	9	42	.60	3.6
5	1	10	.80	8.5	5	2	12	.66	4.8
1	810	813	1.00	0	1	905	905	1.00	0
2	115	607	.19	4.3	2	166	673	.25	3.0
3	44	415	.48	8.4	3	103	473	.47	3.6
4	18	245	.52	12.5	4	57	319	.56	4.6
5	6	112	.47	18.5	5	24	201	.59	7.8

The exhaustion loss, x, is thus greater in the second exhaustion, or after the first evaporation of fog particles, three fourths to four fifths of the number of fog particles precipitated on ions vanishing, while one half to three quarters of the number of fog particles precipitated upon vapor nuclei vanish in the first evaporation, according as the initial number is smaller or greater. The exhaustion loss x is also greater for the case of precipitation on ions, as compared with the precipitation on water nuclei.

Since x is not constant the equation for the second exhaustion should read $n_1 y x \Pi_1$; for the third $n_1 y^2 x x' \Pi_2$; etc.

It will then be found that for ions

$x = .25$	$x' = .80$	$x'' = .76$, etc.
$x = .19$	$x' = 1.20$	$x'' = .62$, etc.

For water nuclei

$x = .55$	$x' = .70$	$x'' = .57$, etc.
$x = .25$	$x' = .88$	$x'' = .80$, etc.

data which are somewhat irregular, but accentuate the importance of the first evaporation.

Special experiments showed that the loss in question is specifically due to the evaporation, and not to time, as, for instance, the loss by diffusion of small nuclei would be. If the time interval between exhaustions is doubled or trebled, etc., there is no corresponding difference in the result.

7. *Decay of Ionized Nuclei in the Lapse of Time.*—If n be the number of nuclei per cubic centimeter, a the number generated per second by the radiant field, bn^2 the number decaying per second, $dn/dt = a - bn^2$. If the radiation is cut off t seconds before exhaustion, $a = 0$, $dn/dt = -bn^2$ or $1/n = 1/n_0 + b(t - t_0)$. Thus the relative nucleation may be found if b is known. If n_0/n is also known, given for instance by the above method of geometric sequences, the absolute nucleation $n_0 = ((n_0/n) - 1)/b(t - t_0)$ is determinable.

The result of this apparently straightforward method leads to grave complications, inasmuch as b is not constant but increases rapidly as the number of nuclei is smaller. Its value moreover is usually twice as large as the electrical coefficient $b = 1.4 \times 10^{-6}$. Thus in Table II,

TABLE II.

n	t	$b \times 10^6$	b[1] $\times 10^6$
83	0	2.9	3.8
38	5	2.1	4.1
27	10	3.3	5.7
14.3	20	4.2	13.4
9.0	30	3.5	
4.6	60	15.0	
1	120		

[1] By taking the first and fourth observations, etc.

which is an example chosen at random from many similar cases. The mean b (excluding the last) is thus .000,0045, at least three times as large as the electrical coefficient.

If but a part n of the nuclei are caught by the exaustion, n' escaping, $-dn/dt - dn'/dt = bn^2 + 2bnn' + bn'^2$. Hence if but $1/m$ of all the ions are captured, the coefficient of decay, b, found should be about m times too large as compared with the true value, or $dn/dt = -mbn^2$. But this fails to explain the increase of b with $1/n$, unless the nuclei grow smaller during decay (or virtually by loss of charge) and so pass beyond the scope of exhaustion. But this is improbable; the experiments show that b increases while the number of nuclei present decreases, no matter whether these reduced numbers of nuclei are due to weak radiation (generating but a few), or to low exhaustion (catching but a few), or to the decay of a larger nucleation (where only a few survive in the lapse of time). If $-dn/dt = -a + cn + bn^2$, where a is the number of ions generated per second by the radiation, cn the number independently absorbed per second and bn^2 the decay per second by mutual destruction, the integrated equation very fully reproduces the observed nucleations n, when $b = .000001$ and $c = .0356$.

Brown University,
Providence, R. I.

THE NARRATIVES OF THE WALKING ON THE SEA.

By WILLIAM A. LAMBERTON.

(*Read April 18, 1907.*)

The narratives of the walking on the sea are found in the first, second and fourth gospels, but not in the third: in the latter, however, this miracle is not merely omitted; there is what seems to me a significant substitute: or perhaps I should rather say a readjustment in the order of events. The passages are Mt. 14:22 ff., Mk. 6:45 ff., Jn. 6:16 ff. Cf. Lk. 9, 18–20.

In all three gospels the narrative follows the miraculous feeding of the 5000, this latter miracle also precedes the passage referred to in Luke. The miracle of the feeding occurs in a desert place on the shores of Lake Gennesaret; the walking on the sea in the departure thence by water, the general impression conveyed being that the boat crosses to the other side of the lake, though there are difficulties as to this. Before taking this up, we may enquire how the company came to this desert place.

In Matthew 14 we are told of the beheading of John the Baptist and in v. 12 we read of his burial by *his* disciples, who thereupon reported the fact (ἀπήγγειλαν) to Jesus, who upon this news received withdraws by boat to the desert place *privately*: hearing of his departure crowds from the towns follow him by land: the place, therefore, might be approached either way.

In Mark 6:30 Jesus's own disciples return from the mission on which he had sent them and report to him (ἀπήγγειλαν, the same word employed by Matthew) their experiences; whereupon he proposes that they go *privately* to a desert place and take a little much needed rest: this is done by boat: again crowds find this out and follow them *up by land* from all the towns, even *getting the start of them* (an important point).

In Luke 9:10 the apostles returned from their mission and recount (διηγήσαντο) all their adventures; hereupon (without reason

assigned) our Lord takes them with him and withdraws to "a desert place of a city called Bethsaida," or according to the better text "into a city called Bethsaida": in any case there is *no boat*, no crossing of the lake; the place is apparently *in* Bethsaida (its territory, of course) on the *west shore*: this at once raises the question, as to which scholars are not at one, whether there was really such a second Bethsaida; for Bethsaida Julias was on the east shore. The crowds notice the withdrawal and follow: again, how is not said.

In John 6:1 we read: Thereafter (a quite indefinite note of time) Jesus departed *across* the sea of Galilea, and a large crowd followed him, because they saw the signs he had wrought upon those that were sick.

The disagreement of Matthew with all the others is very noticeable and is emphasized by the word ἀπήγγειλαν which appears both in his account and in that of Mark as well as by the difference of subject—John's disciples in Matthew, Jesus's disciples in Mark. To be noted also is the fact that the story of John's taking off immediately precedes both in Matthew and Mark, but in the latter is detached from any connection with what follows; while in Luke what precedes is a parenthetical account of Herod's perplexity because of the news he had begun to hear of Jesus: "Herod said: John I beheaded: but who is this," and also (which is significant, as we shall see) the speculations of others: 'John has risen from the dead'; "Elias has appeared"; "one of the ancient prophets has risen again." In John's account this feature of John the baptist does not appear: no reason at all is assigned for our Lord's withdrawal with his disciples.

Now we come to the getting away from the "desert place": We will take Mark's account first, 6:45: Instantly he *compelled* (ἠνάγκασε) his disciples to get into the boat and go ahead *across the lake* to Bethsaida (in Luke they were in or near Bethsaida), and leave him to dismiss the crowd: Then, having dismissed the crowd, he went away *into the mountain to pray*. At a late hour they in their boat were in the midst of the sea and he was on the land. They were having a hard time (he saw them) with their rowing, for the wind was against them. About the fourth watch of the night (3 a. m.) he approached them, walking on the sea.—So far

Matthew and Mark agree, and John differs only in giving Capernaum, instead of Bethsaida, as the goal of their sail.—From what direction does he approach? From behind or from in front? A question of some importance: Matthew gives no indication, nor, perhaps, does John, but Mark implies very clearly that the approach is from behind; for he goes on to say ***ἤθελε παρελθεῖν αὐτούς***. They see him, take him for a spectre and cry out in fright: he quiets them with a word and gets into the boat, wereupon the wind fell (Matthew has added before this the episode of St. Peter's attempt at walking on the water). They were quite beside themselves with astonishment: ***οὐ γὰρ συνῆκαν ἐπὶ τοῖς ἄρτοις***, for their heart was hardened. They push on till they get across and land. Now what does ***οὐ γὰρ συνῆκαν ἐπὶ τοῖς ἄρτοις*** mean? As it stands and where it stands it is, I think, quite meaningless: it was evidently thought to mean something; and indeed, as we shall see, did mean something: it is in fact, I believe, a part of the original tradition which has got misplaced and so lost its meaning; for, really, it has none at all here. There is, of course, no objection to taking ***συνῆκαν*** absolutely; any verb in Greek may be so used; but then the context must make the application clear, as it does not in this case. And ***ἐπὶ τοῖς ἄρτοις***, what shall we do with these words? It has been said that the sense is: the miracle of the feeding should have taught them a lesson that would have prevented all surprise at the walking on the water, but that this lesson had not been learned: but this looks like a desperate attempt to explain the inexplicable; and observe here that Matthew's story of Peter's attempt at imitating the feat quite contradicts this interpretation. I may say, here, that while I believe ***συνῆκαν*** genuine, but misplaced; I also believe that ***ἐπὶ τοῖς ἄρτοις*** should be ***τὰ ἐπὶ τοῖς ἄρτοις***, for, as we shall see, what the disciples failed to understand was *what followed the feeding of the 5000.* If ***ἐπὶ τοῖς ἄρτοις*** be taken as equivalent to ***περὶ τῶν ἄρτων***, as they may, the words are still out of place.

Looking back at Mark's account, we observe that Jesus *hurried his disciples away* with a view to dismissing the crowd: there seems no rationally assignable reason for this method of action. Then our Lord goes up into the mountain to pray: at last we have come to something that is suggestive. Jesus's praying is only thrice re-

corded in Mark: at his first day's work in Capernaum: here; and in the garden of Gethsemane: the first and last mark critical moments. Matthew has this instance and that in Gethsemane: critical moment this last. Luke has mention of Jesus praying at his baptism; at his choosing the twelve; at the Messianic confession; at the transfiguration; when he teaches his disciples to pray: all of them, each in its way, critical moments: there is besides solitary prayer in 5:16, which may be, though it is not clearly so, a critical moment. We may then conclude that the present moment was such a crisis in our Lord's history; just such a moment as would remain fixed forever in people's minds, though (for that very reason) the circumstances might come to be confused and would be very likely to be exaggerated; and with the tendencies then and there prevalent this exaggeration could not help taking the form of miracle, not absolutely invented, however, but springing out of misunderstanding of attendant facts. This will become clearer, if we can, as I think we can, discover the nature of the crisis. The phrase *οὐ γὰρ συνῆκαν* expresses really the attitude at the time of the disciples in the face of this crisis: they did *not* understand it: perhaps, then it is no wonder that Mark did not either.

Let us look at Matthew. All is as in Mark barring three things: (1) Jesus has no thought of passing them: (2) St. Peter will try to walk on the water too (here is exaggeration palpably setting in): (3) So far from showing any misunderstanding or unbelieving wonder, the disciples rather adore the Lord as he enters the vessel and cry aloud "Truly thou art the Son of God." Does not this give us a hint of the critical event, which in the confused tradition that came to Mark had been lost?

But let us look further. Luke has nothing of this walking on the sea, but he has before the feeding of the 5,000 the speculations (Messianic in tendency) of various unnamed persons connected with Herod's court and perhaps outside it; and then after it comes (9:18–20) a record without note of time or place of an event that by Matthew and Mark is given at a later date and in a definite place, viz. at Cæsarea Philippi. And this event is nothing but the Messianic confession made by St. Peter in the name of all the disciples. Compare this with the words just quoted from Matthew, and the

conclusion seems inevitable that the critical event that is at the bottom of the whole narrative, the event which Mark lost and Matthew put in in an unintelligent way, was the confession of the Messiahship of Jesus. Yet were both Matthew and Luke, as well as Mark misled here: for this was the very thing (had Mark only known it) that the disciples "did not understand"; whereas in Matthew and Luke (though there are great differences) they do seem to have understood it. Matthew's mistake is in putting this confession in the mouths of his disciples; Luke's in antedating the scene at Cæsarea Philippi, with suppression, necessitated thereby, of the name of the place.

The account in John may help us out here (6:14). After the miracle of the feeding the *crowd* said: "this is truly the prophet, he that is to come (Cf. Matthew 11:3 when this phrase is used of the expected Messiah) into the world." Jesus saw they were for coming and seizing him "to make him king, and so he withdrew into the mountain in solitude." He does not dismiss the crowd, but flees from their premature intent of proclaiming him Messiah in their own sense. Separation even from his disciples for the moment seemed demanded by the critical situation: he had discerned the purpose of the crowd and left before they had time to declare it; at the same time in a plausible way he got his disciples away from the contagion of the crowd, to which they might have succumbed and thus interfered with his wiser and more prudent plans. The disciples embark and start *across* the lake for Capernaum (not Bethsaida, as Mark has it). After dark there came a high wind and the sea rose. They had made 25 or 30 stadia when they saw Jesus walking ἐπὶ τῆς θαλάσσης: as he neared the ship, they got scared; but he quieted them: *they* wanted (ἤθελον) to take him aboard and instantly their boat was at the shore they were making for. In Mark (alone) we read Jesus wanted (ἤθελεν) to pass by them (and did not); in John *they* wanted (ἤθελον) to take him into the ship, but we are *not* told that he got in. This identity of the verb (ἤθελεν-ἤθελον), though with a different reference, can hardly be accidental. This one word seems to point to identity of original and to the misunderstanding and its cause. Jesus did *not* enter the ship: therefore he did *not* walk on the sea: he was walking on the

shore, on the beach close to and toward the waters edge. ἐπὶ τῆς θαλάσσης may perfectly well mean this, though it *may* have the other meaning also: but only this interpretation seems to cover all the facts as given by John. They have rowed, they don't know precisely how far: they guess 25 or 30 furlongs, but are nearer shore, as the event proves, than they had supposed. Jesus had been alone in the mountain (he had not stayed to dismiss the crowd, therein Matthew and Mark are mistaken, he was too eager to get away from their dangerous presence): after dark, towards morning in fact, he makes his way down to the shore at the point where he looked for his disciples to land (Matthew and Mark both speak of his seeing the boat from the land), thus imitating in the reverse direction the movements of the crowds, when they followed him (and got ahead of him, we remember) to the "desert place." The disciples see him as he approaches the shore and comes nearer to them: they may have thought that he was actually beyond the shore line (they probably did) and coming out to them: they are frightened and, when quieted by his assurance that it is he, their master, they wanted to get him on board; so they put on a spurt in their eagerness and before they knew it (having miscalculated their distance probably in the dim light) they were at the land and there was their Lord. This same conclusion has been reached (but on insufficient grounds) by J. Weiss in his Life of Christ and by Edwin A. Abbott in his Johannin grammar solely on syntactical grounds. The confusion in the tradition, shown by the accounts in Matthew and Mark and the omission by Luke, entirely due to a misunderstanding of what happened, arose in all likelihood from the fact that Jesus hurried (ἠνάγκασε in Matthew and Mark) his disciples away, and hence they were perplexed—did not understand τὰ ἐπὶ τοῖς ἄρτοις = what followed the miracle of the feeding. The wonderful scene they had just witnessed, the abrupt way in which their master fairly drove them into the boat and made them push off, put them into a state of mind where senses and memory at once were likely to play them false, and this seems to have happened.

The clear result is, that there appears to have been a risk of Jesus being seized and proclaimed as Messiah in what may be called the temporary and political sense; this was to run counter to

his purposes, hopes and beliefs and must be somehow escaped. That a critical fact occurred at this time the tradition as given in the synoptics recognized, but the nature of it was missed and the miracle came in to fill the gap; the way being opened for it by the strong, but confused impression made by the whole series of events on the minds of the eyewitnesses, whose senses in the excitement deceived them or were misinterpreted afterwards. Their confusion remained on record in the enigmatical *οὐ γάρ συνῆκαν* of Mark, and the real fact in the transposition of the Messianic confession of Luke.

The significant words about which the whole story crystallized would seem to be: *ἠνάγκασε — ἀπῆλθεν εἰς τὸ ὄρος — αὐτὸς ἦν ἐπὶ τῆς γῆς — εἶδεν αὐτοὺς — ἐπὶ τῆς θαλάσσης — ἤθελεν (ἤθελον) — οὐ γὰρ συνῆκαν — ἐπὶ τοῖς ἄρτοις.*

THE EARLY FRENCH MEMBERS OF THE AMERICAN PHILOSOPHICAL SOCIETY.

By J. G. ROSENGARTEN.

(*Read April 18, 1907.*)

In 1768 Buffon was elected, the first Frenchman to become a member of this Society, and thus the first of a long list of his countrymen chosen for this honorable distinction. In the same year Du Simitiere was elected, still remembered as a local antiquarian, and he brought some French spirit into this Society,—he was diligent in his attendance and active in adding to its collections. In those colonial days naturally the ties with the mother country were very close, and in the same year General Gage and Sir Wm. Johnson were elected. Buffon, Linnæus, elected in 1769, and Benjamin West were presented with the Society's publications. In 1772, Le Roy of the Academy of Sciences in Paris was elected. In 1775 Franklin, President in the chair, presented books by several French authors, Decquemare, Dennis, Rozier, Condorcet, Daubenton, Dubourg, Le Roux, Raynal, Lavoisier, and they were elected. "The calamities of war" interrupted the meetings and they were not resumed until the British had evacuated Philadelphia.

After the meetings were resumed, Gérard de Rayneval, the first French Minister sent here was elected, and a bound volume of the *Transactions* was presented to him, and received with expression of his intention, to forward the interests of the Society in France. He attended the meetings and agreed to forward thanks to Buffon for the gift of his works. The example thus set was followed by the election of his successors, Ternant, Luzerne, Adet, Otto, Genet, Fauchet, and in later years of Hyde de Neuville and Poussin—all French Ministers here. In 1781 La Fayette and his companion in arms Chastellux were elected, and Barbé de Marbois, the French Consul in Philadelphia, whose death the Society mourned in 1837,—in his ninety-fifth year. In 1784 Vergennes, and in 1785 Guichen,

Lieutenant General of the French 'Naval Armies,' were elected. Later Cabanis, Cadet de Vaux, Le Veillard, friends of Franklin during his long stay in Paris, were elected, and St. Jean de Crevecœur, long a resident in this country,—his books made it known abroad, and have recently been republished for their interest and value.

In 1789 Brissot de Warville was elected,—he had travelled in this country and urged French colonies in its western lands,—later he came here as a refugee from the French Revolution, but returned to France and was guillotined. Moreau de St. Mery, a refugee from the French West Indies, was elected in acknowledgment of his contributions to the Society's *Transactions*,—he settled here, opened a book store, was a frequent attendant at the meetings and helped to secure exchanges with French scientific societies.

In 1796 Lerebours and Talleyrand, and in 1800 Dupont de Nemours, and in 1799, Volney—all exiles from France—were elected. Later Lesseps, Consul of France in Philadelphia, and father of the builder of the Suez Canal, was elected, and in 1823 Joseph Bonaparte, and in 1824 his nephew Charles, both exiles after the fall of Napoleon, and long residents here, were elected, with other Napoleonic exiles, Real, Miot de Melito, and in 1829, Hyde de Neuville, the Bourbon minister here.

After the alliance with France, the Society voted that "ten pounds of the best kind of raw silk produced in Pennsylvania be sent to Lyons, there to be wrought in the most elegant manner, and presented to her most Christian Majesty as a mark of very high respect." In 1783 Jefferson moved and Reed seconded and it was ordered that Rittenhouse should make an orrery to be presented to his most Christian Majesty. In 1784 La Fayette, by special appointment, entertained the members with an account of the invisible power called animal magnetism, lately discovered by Mesmer, and soon after Marbois presented the report of the Commissioners appointed by the King of France to investigate the subject.

In 1781 Rochefoucault, Charles, lecturer in experimental philosophy and aeronaut, and in 1791 Du Ponceau, aid to Steuben, and in 1796 Rochefoucault de Liancourt, known by his sympathetic volumes on his travels in this country, were elected. In 1797 Volney

was elected; he returned to France and became a member of the Institute, his book of travels was not nearly so kindly in its tone, and he spoke harshly of his countryman Brissot de Warville for advising Frenchmen to come here. Barbé de Marbois on his return to France was employed in the Foreign office and was an active agent in the sale of Louisiana,—his 'Memoir' was credited with securing Napoleon's approval of the treaty that ceded that vast region to the United States.

In 1789 Quesnay de Beauregard, who had served in the Revolutionary war, presented his elaborate Plan of the Academy of Sciences and Belles Lettres, established by him in Richmond, Va.; it was a very broad scheme for a sort of exchange bureau and clearing house of scientific and literary intelligence between the United States and France and other European countries,—the French Revolution put an end to it;—he was a grandson of Quesnay, one of the leaders of the French economists,—his son wrote on the Constitutions of Pennsylvania and Massachusetts, and his grandson was the prosecuting attorney against Boulanger.

Le Gaux was elected in 1789, no doubt in recognition of his efforts to establish vineyards at Spring Mills, near Philadelphia.—Du Ponceau, who was elected in 1791, began life as a student for the priesthood, but came here at the suggestion of Beaumarchais, as secretary and interpreter for Steuben,—he became a member and later a leader of the Philadephia Bar, president as well as a frequent contributor to the proceedings of the Philosophical Society, and was elected a member of the French Institute in recognition of his writings on Indian languages, etc.

Many of the French exiles found, as Pontgibaud, one of them, said, an ark of safety in Philadelphia, and most of those then or later famous, were elected; at one time so many attended that they addressed the society in French, and here at least there were representatives of all the conflicting elements of French politics, Royalists, Girondists, republicans of every opinion, and they met apparently in great harmony in these peaceful halls, discussing scientific questions. Dupont de Nemours had filled many important positions in France, had helped Vergennes negotiate the Treaty of Peace with Great Britain, was a leader among the economists of France,

and president of the French Constituent Assembly, and while his sons established in this country the business still carried on by their descendants, several of them became members too,—he returned to France and filled important posts. He wrote at the suggestion of Jefferson, an essay on Education in the United States, in which he presented a plan for primary, secondary and higher schools, colleges and universities.

With the nineteenth century began the election of many leaders of science in France,—Roume, Delambre, Destutt de Tracy, Lasteyrie, Michaux, Vauquelin, Deleúze, Pougens, Remusat. Money was subscribed by the Society toward the expenses of Michaux's western explorations, and later for a statue of Cuvier in Paris. Wm. Maclure, formerly a merchant of Philadelphia, after a long residence abroad, returned, bringing with him a corps of naturalists, to help him in a plan for a geological survey of the United States,—one of them, Le Sueur was elected a member in 1817; trained in the Jardin des Plantes in Paris, he contributed many papers to the scientific societies abroad and here,—joined Maclure in founding the Academy of Natural Sciences and was active in both bodies. Later he went with Maclure to New Harmony, Indiana, and continued his scientific studies in the then far west, and returning to Philadelphia, taught drawing, was a frequent attendant at the meetings of this Society, and at last returned to France, to take charge of the Natural History Museum of Havre, where he died in 1846.

In 1803 the National Institute of France promised, as successors of the French Academy of Sciences, to resume correspondence and exchanges, established by Franklin during his long stay in Paris. Franklin left by will of this Society, 91 volumes of the History and Transactions of the Royal Academy of Sciences of France, and after his death, it bought from his library many French scientific books, and by Hassler's aid, completed many of the serial publications of French scientific societies, which now form an important part of its large and growing collection of works of that kind.

At a later time at a meeting at which Joseph and Charles Bonaparte attended, they and Le Sueur and Du Ponceau spoke of the earlier days of frequent attendance of French members and visi-

tors. It was here that Talleyrand collected material for the papers he read after his return to France, before the Institut, in which he spoke in flattering terms of his stay in this country,—mentioning his asking a chance acquaintance, Benedict Arnold, not knowing him, for letters of introduction, and Arnold's reply that he was the only American who could not help him with his countrymen. Hyde de Neuville, a royalist exile, lived here for some years, after the restoration of the Bourbons returned to France, filled some important posts, then came back as French Minister,—was kept busy watching the Napoleonic exiles, some of them alarming him by their military colony in Texas, and wild schemes for a French Empire in Mexico, with a Bonaparte to reign over it;—he politely returned to Joseph Bonaparte a portrait of Napoleon found at the French Legation in Washington,—returned to France, was Minister of Foreign Affairs under Louis Philippe, and left an Autobiography full of incidents of his life here.

Later King Louis Philippe, A. Julien, Stanislas Jullien, Larrey, Roux de Rochelles, Guizot, de Tocqueville, Poussin, French Minister to the United States, Leverrier, Pouchet, Michel Chevalier, Brown Sequard, Elie de Beaumont, Milne Edwards, St. Claire Deville, J. B. Dumas, Verneuil, Claude Bernard, Lesquereux, Renan, Boucher des Perthes, Gasparin, Mariette, Carlier, Leon Say, Broca, Viollet le Duc, Claude Jannet, Paul Leroy Beaulieu, Rosny, Pasteur, Levasseur, Duruy, Nadillac, Taine, Berthelot, George Bertin, Maspero, Poincaré, Becquerel, Darboux, were among the representative Frenchmen of science and letters elected to membership in this Society, thus perpetuating the long roll of French members which began with Buffon. This goodly custom will no doubt long continue as a proof that the alliance of France and the United States, to which this country was so largely indebted for its independence, will be perpetuated by inviting to membership in this Society the leaders of French intelligence in every field of research.

In the collection of this Society there is manuscript by Mr. Samuel Breck, a member from 1838 until his death in 1862, in his ninety-first year, in which he gives his recollections of some of the early French exiles, members of this Society. He speaks of these too, in the volume of his "Recollections," published in Philadelphia

in 1877. He mentions the fact that Talleyrand, like others of his fellow exiles, notably Volney, took the oath of allegiance to the State of Pennsylvania. Talleyrand speculated in land and stocks, and made money, thanks to the help of William Bingham, then the richest man in this country. It is characteristic that although Talleyrand brought a letter from Lafayette to Washington, the President declined to receive him until he was about to return to France, to begin that diplomatic career which made him so conspicuous in European affairs for many years.

Mr. Breck also speaks sharply of Volney, who earned his living here by teaching, and his unfavorable opinion is confirmed by the contemporary report of an English visitor, Thomas Twining, who thought that Volney's temper was soured by his loss of power in France,—on his return he attained a position of importance and yet in his "Travels," said little that was kind of the country that had given him a safe refuge. This too was true of Brissot de Warville in his "Travels,"—but he, poor fellow, went back to France too soon, and ended his life under the guillotine.

Mr. Breck says that Rochefoucauld and the Orleans princes took their enforced exile very good naturedly. Chastellux, who had served under Rochambeau, as well as his comrade, Lauzun, and a later exile of a very different type, Brillat de Savarin, better known by his book on cooking than by his more serious work as a judge, all said kind things of the country and people who gave them shelter in their distress. Many of the French travellers who have visited and written about this country, were members of the Philosophical Society, and from its large and valuable library, drew much information for their writings.

The publication of the writings of Franklin, edited with fidelity by Professor Albert H. Smyth, one of our members, enables us to see in Franklin's vast collection of his papers preserved here, how largely he influenced and was in turn influenced by his French associates. Many of his friends in Paris were scientific men of great distinction and leaders of public opinion there and many of them became contributors by papers, gifts of pamphlets and books to this Society, and no doubt at his suggestion, were elected members, and thus became interested in its work. The example then of our

great founder and of the many notable Frenchmen elected members from his day on, may well inspire this Society to continue and increase its activity by electing other Frenchmen sharing in its task of promoting useful knowledge.

Note: At the General Meeting of the Society held April 20th, 1907, M. J. J. Jusserand, French Ambassador at Washington, and author of many valuable works, was elected a foreign member of the American Philosophical Society.

THE EFFECT OF IMPERCEPTIBLE SHADOWS ON THE JUDGMENT OF DISTANCE.

By EDWARD BRADFORD TITCHENER
AND
WILLIAM HENRY PYLE.

(*Read April 18, 1907.*)

Some six years ago, an investigation was published under the above title from the Psychological Laboratory of the University of California.[1] Briefly stated, its thesis was that a motive to optical illusion, although so faint as to be wholly imperceptible to the observer, is nevertheless effective in the determination of judgments of visual distance. One is required to compare, under certain methodical conditions, the lengths of two contiguous sections of a straight line. To all appearances, the stimuli are perfectly simple: one sees, drawn horizontally upon a white background, a thick black line which is bounded and divided by three vertical black marks; and the problem is, in successive observations, to report upon the equality or difference of the two sections thus displayed. The peculiarity of the experiment lies in the fact that the stimuli are only apparently simple. In certain series, not known to the observer, the experimenter throws upon the white background angular shadows, disposed in such a way as to convert the two lengths of line into the two parts of the Müller-Lyer illusion. These shadows, be it repeated, are so faint that they are never, even under the greatest strain of attention, visible to the observer. Yet they have their due effect: the judgments of length of line prove to be subject to a constant error, whose sign, *plus* or *minus*, reflects the tendency of the motive to illusion.

This contention is, in itself, startling enough. A great deal has been written, of recent years, about the subliminal and the subconscious, and many wonderful things have been declared in their name. Where the phenomena are obscure, the definitions arbitrary,

[1] K. Dunlap, in *Psychological Review*, VII., 1900, 435 ff.

and the training and temperament of the writers markedly diverse, much variety of opinion will ensue, and dogmatism is altogether out of place. But the case now under consideration is unique.[1] It is asserted that in straightforward psychophysical method-work, done under strict conditions, the eye may be solicited by lines which it cannot see, the judgment warped by a motive which is neither in consciousness at the time nor ingrained by habit in the nervous system of the observer.

A principle so revolutionary—for the whole environment is full of subliminal influences, which experimental psychologists have systematically neglected!—must, one would think, be based upon unequivocal evidence. Hardly less surprising, now, than the conclusion itself are the numerical results which claim its acceptance. The standard length of line, throughout the experiments, was 25 cm. The errors of judgment ascribed to the illusion motive vary between the extreme limits of 1.05 mm. and 0.10 mm.[2] "The difference," as the author admits, "is slight; but," he adds, "we should hardly expect to get more than a slight effect from the shadows under the circumstances."[3] The effectiveness of an optical illusion, that is to say, stands in direct proportion to the clearness of contour of the figure shown. Is it not more reasonable to suppose that an illusion motive, if effective at all, will be effective at full strength? Or, at any rate, is not this alternative supposition worthy of experimental test?

It is, however, easier to accept a statement once made—especially if the content of the statement fall in with our immediate intellectual purpose—than critically to estimate the value of the evidence upon which the statement rests. And Dunlap's thesis has, accord-

[1] Dunlap finds a parallel to his own results in the experiments of C. S. Pierce and J. Jastrow on small differences of sensation (*Memoirs of the National Academy of Sciences*, III., i., 1884, 75 ff.). There is however, no resemblance whatever between the two investigations. As the latter has been discussed by G. E. Müller in 1904 ("Die Gesichtspunkte und die Tatsachen der psychophysischen Methodik") and by Titchener in 1905 ("Experimental Psychology," II.), and as it contains nothing which can invalidate the canons of psychophysical method, we leave it here out of account.

[2] Dunlap, *op. cit.*, 448. The figures given are: 0.62, 0.40, 0.17, 0.83, 0.18, 0.10, 1.05 and 0.72 mm.: an average of half a millimetre!

[3] *Op. cit.*, 450.

ingly, found its way, as matter of proved fact, into the current 'literature' of psychology.[1] This circumstance alone is a justification for the reopening of the whole question.

Apparatus and Method.

It is clear that the conditions of the experiment may be met in two different ways. Either the white background may be made translucent, and the shadows shown from behind by transmitted light; or the background may be made sensibly opaque, and the shadows thrown upon it from the front. Both forms of apparatus were employed by Dunlap: our own experiments, for reasons which will be given later, were performed only with an apparatus of the first type. In order that the two sets of results might be comparable, we at first set up this apparatus in accordance with Dunlap's description, and reproduced his method of work.

A sheet of white bristol-board, 58 by 72 cm., was mounted horizontally in a black wooden frame. Across the middle of the sheet was drawn a black line, 1 mm. in width, which was crossed at the centre by a vertical black line, 0.75 mm. wide and 17 mm. long. To the sides of the frame, at the level of the horizontal line, were fastened guides, in which ran small rods of blackened steel: the rods could be drawn in or out along the line, and were of course invisible against it. The inner ends of the rods carried vertical strips of black paper, 2 mm. wide and 10 mm. long. These strips, like that at the centre, extended equally above and below the horizontal line; and the three together marked off the two sections of that line whose lengths the observer should presently be called upon to compare. A mm. scale, attached to the frame above the rods, and a small marker on the rods themselves, made it possible to set the limiting strips, with accuracy, to any required position.

[1] We may mention G. M. Stratton, "Experimental Psychology and its Bearing upon Culture," 1903, 88 ff.; J. Jastrow, "The Subconscious," 1906, 417 ff.; J. B. Pratt, "The Psychology of Religious Belief," 1907, 20. Dunlap's results are accepted by M. Meyer ("Aus den Versuchsergebnissen geht mit Deutlichkeit hervor, dass auch in solchem Falle die Illusion stattfindet"), in [illegible] XXXV., [illegible], 200; by A. Meyer, in [illegible] IV., 1907, 80 f.; by the anonymous reviewer in [illegible] N. S., X., [illegible]; and, although with more reserve, by J. Philippe, in [illegible]. We are not aware that they have as yet been incorporated in any formal text-book of psychology.

The shadows were cast by angular pieces of stiff black cardboard (angular magnitude, 60°; length and width of legs, 45 and 5 mm. respectively). One of these was fastened to the back of the sheet, its vertex coinciding with the centre of the central vertical line on the front. The other two moved in or out with movement of the limiting strips. The arrangement was simple: the rods carrying the strips were bent round, to the back of the frame, and there passed through guides placed at the level of the front guides and strictly parallel to them. The cardboard angles were attached to the inner ends of this second pair of rods, with their vertices at the centres of the strips. Whenever, then, the limiting strips were moved, their angles moved with them, and strip in front and angle behind maintained always the same relative position.

The apparatus thus constructed was set up on a table in a dark room. Its front surface was illuminated by two hooded incandescent lamps, placed symmetrically on either side and at equal distances from the sheet; its back surface was illuminated by a single hooded lamp, placed opposite the centre of the sheet. This third lamp was controlled by a rheostat, and all three were on the same electric circuit. The bulbs were of ground glass, and the light of the lamps was further diffused by sheets of tissue paper.

The procedure was now as follows. The observer, seated before the apparatus, was left in the dark for 15 minutes, in order that his eyes might be properly adapted for the experiments. The lights were then turned on, and the experimenter held up, directly behind the frame, a circle or a skeleton square cut from black cardboard. The intensity of the light at the back was slowly reduced, until the observer was just unable to detect the shadows cast by these figures. Or, rather, the reduction of the light was arrested at a point somewhat short of this: at the point, namely, when the observer declared that there might perhaps be a shadow there, on the white background, but that he could not possibly decide whether it was the shadow of a square or of a circle. We may say at once that the arrest of the rheostat at this point caused us some inconvenience in the experiments proper, since it not infrequently happened that the observer remarked, in the course of a series, that he thought he saw a shadow on the white sheet: in which case the

series was thrown out, and repeated later on. We wished, however, to give the subliminal shadows every chance to produce their effect, and were therefore content to run this risk of additional work.

Having regulated the intensity of the light behind the apparatus, the experimenter affixed the Müller-Lyer angles to the sheet and rods. The constant or standard line, which was placed as often to the right as to the left, was 25 cm. in length. The variable line was set, at the beginning of a series, to appear either as distinctly longer or as distinctly shorter than the standard; and the limiting strip was moved in or out, by steps of 1 mm. and at intervals of 15 seconds, until several judgments had been recorded of the opposite tenor to that with which the series began. Every series taken with the angles was paired with a precisely similar series taken without them.

The order of experimentation was, so far as possible, left to chance. Thus, the position of the angles for a given paired series, as open or closed, was determined by lot. There were as many series beginning with "longer" as with "shorter," but their distribution was also determined by lot. Finally, while the members of a paired series were always given together, chance was allowed to decide whether the shadow-series should precede the shadowless, or conversely.

The judgments of the observer referred always to the variable line, and took the form "longer," "shorter," and "equal" or "doubtful." The middle point of the region of doubt and equality was taken as the mean equality point of the single series, and this was compared with the mean equality point of the other member of the pair[1]. Five observers took part in the experiments: Mr. L. R. Geissler, Mr. C. R. Hugins, Professor T. A. Hunter, Mr. W. H. Pyle and Miss E. A. Smith. All except Mr. Hugins had had extended training in psychological observation.

[1] In the foregoing, we have closely followed Dunlap: *op. cit.*, 436 ff. The principal differences of procedure appear to be these: that we gave our observers a fairly extensive preliminary practice; that we allowed a period for adaptation of the eyes to the dark; and that we placed the standard line as often on the one side of the figure as on the other (for Dunlap, the standard was always on the left).

Experiment I.—What, now, of the results? Dunlap quotes no figures. He merely says that "a set was counted 'for' or 'against' the illusion according as the difference between the mean equality points was or was not in the direction which would correspond to the possible effect of the illusion-figure."[1] And he tabulates his results as follows:

Observer.	Paired Series.	For Illusion.	Against.	Neutral.
A	23	14	8	1
R	11	9	2	0
S	13	8	5	0

Nothing is here said of the magnitude of the illusion-effect. If, however, this point is disregarded, and our own results are treated as Dunlap prescribes, we obtain the following table:

Observer.	Paired Series.	For Illusion.	Against.	Neutral.
G	8	4	3	1
Hg	12	5	5	2
Hn	12	3	5	4
P	10	4	4	2
S	12	4	7	1

It is plain that the two sets of results are not in agreement. Since apparatus and method were practically the same, and care and skill in the conduct of the experiments may be assumed to be equal, we can only conjecture that the positive testimony of Dunlap's series is due to chance, operating on a small group of observations.

Experiment II.—It would, naturally, have been simply a matter of time to extend these series to a point at which the effects of chance should be ruled out. It seemed advisable, however, to modify the procedure. Dunlap himself refers to the experiments above reported as "preliminary to the investigation proper," and asserts that the apparatus was "not very satisfactory in its operation":[2] though he gives no details. We found two principal sources of error. On the one hand, we feared that the presence or absence of light behind the screen, as the change was made from shadow-series to shadowless, might influence the observer's judgment. We

[1] *Op. cit.*, 439.
[2] *Op. cit.*, 439, 436.

decided, therefore, to keep the illumination constant, and to remove and attach the Müller-Lyer angles as occasion demanded.[1] On the other hand, there can be no doubt that the direct pairing of two precisely similar series is methodically indefensible; the observer tends to say 'equal' or 'doubtful,' in the second series, at about the same point at which he passed this judgment in the first.

The method that would naturally be employed in an investigation of this sort is the method of constant-*R* as applied to the determination of equivalent stimuli.[2] We desired, however, to keep as closely as possible to the method chosen by Dunlap, and accordingly proceeded as follows. For each observer we made out a set of twenty-four single series. In eight series, the angles were used with the "illusion long" as the variable. In eight series, the angles were used with the "illusion short" as the variable.[3] In the remaining eight series, the illusion-angles were not used. On the basis of the previous experiments we selected eight different starting-points for these series, four lying well without and four well within the point of subjective equality. The order of the single series was decided by chance; the variable was shown as often on the right as on the left. The intervals between series were kept constant, so that the observer had no means of knowing whether or not the experimenter changed the apparatus. For the rest, the observations were taken and the calculations made as in the preliminary experiments.

The table shows the results obtained from five observers: the *G*, *Hg*, *Hn* and *P* of the former experiments, and Mr. R. W. Sailor, a trained observer.

[1] It must be remembered that, though the observers were not informed of the object of these experiments, and (with the exception of *P*) were unfamiliar with Dunlap's work, they nevertheless received a fairly definite suggestion from the preliminary tests with the circle and skeleton square. No one of them reported any difference in the appearance of the white background from series to series. Two, however, differentiated the series by the glow of light shed upon the table by the back lamp when this was turned on. We arranged black curtains to cut off this diffused light; but there was still a faint glow upon the walls of the room.

[2] Titchener, "Experimental Psychology," II., 1905, i., 104; ii., 258.

[3] Dunlap, *op. cit.*, 437. In Dunlap's use of the phrases, the reference is always to the left or standard segment of the line.

Observer.	Average Setting of Variable with		
	Illusion Long.	Illusion Short.	No Illusion.
G	249.8 ± 2.5 mm.	251.4 ± 2.8 mm.	250.1 ± 2.5 mm.
Hg	252.8 ± 1.8	249.5 ± 1.8	249.8 ± 1.4
Hn	251.7 ± 2.0	246.6 ± 0.9	249.2 ± 2.5
P	250.0 ± 0.9	250.0 ± 1.1	249.6 ± 2.1
S	250.0 ± 1.5	248.0 ± 2.2	250 5 ± 2.0

If the illusion motive is effective, the figures of the first column will be less, those of the second greater, than the corresponding figures of the third column. The observers *Hg* and *Hn* thus give negative results; *P* and *S* give one positive and one negative; and *G* alone gives two positive results. But a glance at the magnitude of the differences, as compared with that of the *MV*, shows the absurdity of drawing any conclusion of this sort from the results.[1]

Experiment III.—In view of the negative outcome of this second set of experiments, it seemed necessary to raise the question suggested in the introduction to this paper: the question whether an illusion motive, if effective at all, must not be effective at full strength. Have we any reason to suppose that a dim illusion-figure will produce a small effect, and a clear illusion-figure a marked effect upon the observer's judgment? We approached this problem as follows.

The horizontal line and its three markers were removed from the white bristol-board, and their place was taken by a length of fine black sewing thread. To render the shadows of the Müller-Lyer angles intensive, we placed three lamps behind the apparatus,

[1] The averages, as was stated above, have been calculated in Dunlap's way. We have submitted the figures to all the other forms of methodically permissible treatment known to us, and can discover no trace of the influence of the illusion motive.

Jastrow declares (*op. cit.*, 417) that if, after experiments with the Müller-Lyer figure, one proceeds to experiment upon the estimation of visual distances in Dunlap's way, *i. e.*, with "the shadow-strokes reduced to such a degree of faintness that the eye fails to detect their presence," the observer will judge "naturally with diminished confidence" as to the relation of the two lines. Why? If the shadows are not seen, how can the observer's confidence be diminished? He is simply called upon to compare two horizontal lines.—On the general question of 'degree of confidence,' see esp. G. E. Müller, "Gesichtspunkte u. Tatsachen der psychophysischen Methodik," 1904, 21 f.

and darkened the two lamps in front by curtains of black cloth. Under these conditions, the shadows stood out sharp and crisp upon the thread line. To render the shadows faint, we reduced the intensity of the single light at the back, as in the previous experiments, until the angles were barely perceptible. These faint shadows were, of course, stronger than the shadows of the earlier experiments. In the latter, the light was so far reduced that, at best, only shapeless patches of bright grey could be discerned upon the white background. In the present series, the shadows were still seen as angular strips of very light grey. At the same time, they were so faint that they frequently faded out, in whole or part, during the progress of a series. If, then, the efficacy of the illusion motive varies with intensity of stimulus, there should be a wide difference in the results of experiments carried out at these two extremes of the intensive scale.

As the illusory effect of the Müller-Lyer figure may decrease with practice,[1] we thought it well to secure the services of naive and untrained observers, in order that we might compare their judgments with the judgments of some of the trained observers already at our disposal. Experiments were made with two unpractised observers, Miss G. M. Fairlamb and Mr. G. W. Hau. Of *H*'s results we shall speak presently. The average effect of the illusion motive in the first eight series taken with *F* was

Shadows Weak.	Shadows Strong.
30.6 mm.	41 mm.

There was thus a distinct difference in favor of the stronger shodows. Nevertheless, the high value of the *MV* in the series with weak shadows, the length of time required for the passing of judgment in the critical zone, and the observer's complaints of the fluctuating character of the shadows, showed that the two series were not

[1] C. H. Judd, *Philosophical Review*, ix., 1902, 27 ff. Judd's law of decrease with practice is not universal, as is proved by the fact that the magnitude of the Müller-Lyer illusion-effect in the case of one of the writers (T) has shown a slight but constant *increase* with increase of practice. Cf. V. Benussi, "Zur Psychologie des Gestalterfassens," in A. Meinong's "Untersuchungen zur Gegenstandstheorie und Psychologie," 1904, 331 f. In general, however, we agree with Judd and F. Schumann (*Zeits. f. Psych. u. Physiol. d. Sinnesorg.*, XXX., 1902, 263 f.) that, with spontaneous reaction to the figure, practice tends to reduce the illusion-effect.

strictly comparable; we had made the weak shadows too weak for our direct purpose. At all events, the illusion-effect of 30.6 mm. with the weak shadows is a large effect, and it is hardly possible that the further weakening of the shadows, to the point realised in the previous experiments, should, if the illusion motive is effective at all, reduce this effect to a magnitude smaller than the *MV* of practised observers. To make assurance doubly sure, we took twenty-four series of experiments with *F* under the original conditions, and obtained the results:

Average Setting of Variable with Illusion Long.	Illusion Short.	No Illusion.
249 ± 2 mm.	249.7 ± 1.2 mm.	250.5 ± 1 mm.

That is to say, there is no evidence of any effect at all exerted by the imperceptible shadows.

F's practice was continued, until the magnitude of the illusion-effect was approximately the same for her as for our more practised observers. We finally obtained the following average values for the illusion:

Observer	Shadows Weak.	Shadows Strong.
F	9.1 mm.	12.7 mm.
G	12.1	10.3
P	11.1	16.9

It is an irony of chance that the observer *G*, whose results have so far been (in Dunlap's sense) accordant with the hypothesis of the influence of imperceptible shadows, should here give a larger illusion-effect with the faint than with the strong shadows.

The table is not altogether satisfactory, because the weak shadows were, throughout, fluctuating; we had made them a little too weak for comparative purposes. But the main point is clear: even on the very edge of imperceptibility, the weak shadows have an effect that is of the same numerical order as the effect of the strong shadows, and this with observers whose judgments show no influence of imperceptible shadows.[1]

[1] The figures of the table represent the average value of the illusion-effect as drawn from 16 methodically planned series, in 8 of which the variable gave the "illusion long," and in 8 the "illusion short." The smaller values obtained for the illusion-effect with shadows weak, in the cases of *F* and *P*, are accounted for by the fact (attested both by measurement and by introspection) that in a few series the tips of the shadows were so faint that the illusion motive was disregarded by the observer.

ent IV.—*H*'s results were, from the first, radically dif- n those of *F*. Whereas *F* showed an initial illusion-effect mm., *H*'s first two series, with the shadows strong, gave ne of

Illusion long........................248 mm.
Illusion short......................255 mm.

and later series yielded results of the same order. That is to say, the shadows, in both sets of experiments, were practically ignored. *H* explained in the vernacular that "we couldn't fool him with those shadows"; and the event proves him right.

These particular shadows, it will be remembered, lay upon the line of sewing thread, which was itself relatively narrow, and which had no vertical markers. If the shadows might be ignored, or abstracted from, under conditions thus favorable to their influence, it seemed to us that they might still more easily be ignored under the conditions of the earlier experiments, in which the horizontal line was relatively wide, and the three vertical markers stood out clearly upon the white background as the limits of the compared distances. To test this theory, we restored the apparatus to its original form, and made a series of experiments with one of our practised observers, Mr. Sailor. The instructions were that no attention should be paid to the shadows, but that judgment should be passed upon the lengths of the lines simply by reference to the position of the vertical markers. The results were as follows:

	Setting of Variable Line with Shadows Weak.	Shadows Strong.
Illusion long......	250.5 mm.	251 mm.
" "	248	247
Illusion short......	251	248
" "	252	249

The moral is clear. The observer is here able, by direction of attention, to resist the solicitation of a strong illusion motive, clearly presented. So much the more then will he, under the conditions of our first experiments, resist the solicitation of an illusion motive which he cannot see, of whose presence in the particular series he is entirely ignorant, and which is left out of account in the instructions given him by the experimenter.[1]

[1] *H*'s tendency spontaneously to ignore the illusion-motive from the outset is an interesting fact. One of the writers (*T*) has come across other

Summary and Criticism.

We have now shown:

1. That imperceptible shadows, raised almost to the limit of perceptibility, exert no influence upon the judgments of distance passed by five observers;

2. That shadows, so weak as barely to hold their form distinct, exert an influence upon judgment comparable with the influence exerted by strong and clear shadows;

3. That it is possible, by voluntary direction of attention, to free the judgment from the influence of a clear and strong illusion-motive.

In other words, we can find no experimental confirmation of Dunlap's results, and we believe that a more exact analysis of the conditions of his experiment shows these results to be illusory. We suggest, further, that imperceptible shadows, if they affect judg-

instances of it; but it does not appear to be common. Judd remarks (*op. cit.*, 38) that "early in the practice series both observers noted the feeling of having succeeded in abstracting from the oblique lines. That they had not done so appears in the fact that the illusion continued in almost its full original strength." There are, evidently, individual exceptions to the general mode of apprehension of the regular Müller-Lyer figure by unpractised or little practised observers.

We could not, then, generalise from *S*'s results, if the figure employed had been the regular Müller-Lyer figure. But, as is stated in the text, the figure employed was in so far different that the three vertical markers on the front of the screen afforded definite resting-places for the eye. The shadows were not, so to say, integral parts of the total figure shown; that figure was, first of all, a black line, with a long thin vertical at its centre, and short thick verticals at its two ends: the shadows were secondary. Under these conditions, abstraction from the shadows, with definite instructions from the experimenter to that effect, offers no special difficulty: *S*'s results were, as a matter of fact, confirmed by unsystematic experiments made with two other practised observers.

H evidently represents a case of self-suggested *A-Reaktion* (in Benussi's terminology), that is, of the reaction in which "die Versuchsperson . . . die Hauptlinie der Figur als einen selbständig und isoliert vorliegenden Gegenstand erfassen muss" (*op. cit.*, 310). He would not be 'fooled' by the shadows; he directed his attention to the horizontal line. His and *S*'s results agree with those of Benussi's prescribed *A*-reactions: "in der Tat hat Judd ungefähr 1500 Einstellungen gebraucht, um die Täuschung auf einen Wert zu bringen, der sich bei vorgeschriebener A-Reaktion nach *einigen* Einstellungen erreichen lässt" (*op. cit.*, 332).

ment at all, must affect it by more than the 0.5 mm. in 25 cm. which is the average of Dunlap's observations.

It remains, now, to seek an explanation of Dunlap's positive results. We said above that the method pursued in these experiments is not the method best suited to the problem. Similar exception may be taken to the apparatus. For while the setting of the distances is sufficiently accurate, the illumination is not under measurable control. We have spoken of "barely perceptible" shadows, but we have not been able to specify the amount of light thrown upon the back of the apparatus in any given series. We do not think that this lack of quantitative control at all invalidates our results; but we confess that, from the physical point of view the experiment would have been prettier had such control been exercised.

Dunlap's work, after his preliminary experiments, was done with an apparatus in which the shadows were thrown upon the white screen from in front, and the amount of light employed to produce them was measured by means of an episcotister.[1] We did not reproduce this apparatus, partly because our results seemed conclusive, partly also because the apparatus is cumbrous, and appears likely to introduce new sources of error. We have still however, to account for the positive outcome of Dunlap's investigation.

We grant, at once, that we can give no single or convincing explanation of these figures. All that we can do is to suggest the various possibilities of explanation that have occurred to us. Thus (1) the average illusion-effect is, as we have pointed out, 0.5 mm upon a standard line of 25 cm. Dunlap nowhere gives his *MV* but there are indications in the paper that it must have been, at the least, as large as our own.[2] An illusion-effect of such inconsiderable amount, absolute and relative, might very well be ascribed to chance. (2) It is conceivable that the figures rest upon a miscalculation; experimental psychologists, from Fechner down, have been liable to slips in addition and subtraction. Nor is this suggestion as gratuitous as it may at first sight appear; for the paper

[1] *Op. cit.*, p. 440.
[2] *Op. cit.*, 445 f., 447 f.

shows at least two instances of careless handling. If the two plates on pp. 449, 451 are compared with the description on pp. 452 f., it will be seen that the lower diagrams of each plate have been interchanged: Figs. 7 and 8 should be Figs. 11 and 12, and conversely.[1] And again: if the table on p. 448 is scrutinised, two mistakes will be noticed. The difference between + 2.65 and + 1.75 is given as — .10; the difference between + 1.06 and + 0.78 is given as — .72. It is easy to read 2.65, 2.75, and 1.06, 1.78: but then the differences, instead of being *minus*, are *plus*,—that is to say, tell against Dunlap's conclusion. At all events, something is wrong, either with the principal figures or with their differences. (3) Dunlap's observers showed a progressive change of judgment throughout the experiment. Whatever may be the explanation of this change,[2] he tells us that three of his observers overestimated the right segment early in the experiment, and later underestimated it; while the fourth observer, "with a single exception, overestimated the right segment throughout the experiment, rather more

[1] Dunlap says that 5, 8, 9 are indifferent; 6, 10, 11 faintly in accord, and 7, 12 in striking agreement with his hypothesis. If we read 5, 12, 9; 6, 10, 7; and 11, 8, we bring the plates into accordance with the text. These changes, however, mean the replacing of the present 7, 8 by 11, 12, and conversely.

[2] The explanation must probably be sought in a general tendency of judgment, complicated by preferential direction of attention: it will be remembered that the experiments were doubly one-sided, in that (1) the standard line was always shown on the left, and (2) the variable was always increased from "shorter" to "equal," never reduced from "longer." The shift of judgment might have been checked by suitable instruction from the experimenter (Titchener, "Experimental Psychology," II., 1905, ii., 305 f.). How far practice was involved it seems impossible to say.—It is, of course, theoretically possible that the minute values obtained by Dunlap for the illusion-effect are due to a very high degree of practice with the Müller-Lyer figure. We have not seriously considered this possibility, (1) because Dunlap says nothing of preliminary practice; (2) because he gives no intimation that the illusion-values of his Table I. were different in kind from those of Table IV (see p. 450): (3) because he definitely ascribes the small values to the "circumstances" of the experiment, i. e., to the subliminal character of the shadows (p. 450): and (4) because, in view of Judd's and of our own results (our observer *G*, in particular, has had extended practice with this illusion-figure), we do not consider that Dunlap's experiments were numerous enough to reduce the illusion-average to 0.5 mm.

toward the last than the first."[1] For this reason, "in computing the averages, those for the shadowless series which were taken at the same time as the series with the illusion 'long' were kept separate from the averages for the shadowless series taken at the same time as the series in which the illusion was 'short.'"[2] It is clear, however, that shadowless and shadow-series could not, in strictness, be taken at the same time; they were taken successively. And, as the change of judgment was progressive, Dunlap's averages are used for the comparison of results that are, in strictness, incomparable. Under these circumstances, it is entirely possible that chance, in determining the order of the single series, may have played, so to say, into the hands of the illusion motive. (4) Dunlap does not tell us how he measured his lines: whether behind the screen, from angle to angle, or in front of the screen, from marker to marker. If he measured behind the screen, then the movement of the right-hand angle only every fifth time that the right-hand marker was moved[3] would introduce a constant error, which must, necessarily, operate in the same direction as an effective illusion motive. (5) Lastly, it may be observed, in general, that observers in method-work, however well-meaning, fall easily into a reliance upon secondary criteria; and that an apparatus of the kind used by Dunlap might easily admit this source of error. This suggestion must remain vague, since, without actual trial of the apparatus, we cannot say what the nature of the secondary criteria would be; the suggestion itself, however, does not seem to us unfair, whether in the light of our own experience or in that of Dunlap's account of his procedure.

To attempt, in this manner, to explain away the results obtained and the conclusions offered by another investigator is not a grateful task. Some of our suggestions may be put out of court at once by a word of explanation from Dunlap. The suggestion of a possible miscalculation —made by us, be it repeated, only on the ground of positive evidence of careless treatment—should be offset by the admission that Dunlap planned his experiments carefully, and with

[1] *Op. cit.*, 447 f.
[2] *Op. cit.*, 448.
[3] *Op. cit.*, 442.

due regard to the dangers of bias and partiality. But in any event, whether or not we have hit upon the right explanation of his results, there can be no doubt that these results are themselves untenable. Our own experiments point unequivocally to the one conclusion that, if the subconscious is to be received into experimental psychology at all, it must find some other means of access than these imperceptible shadows.

NOTE AS TO THE MEASUREMENT OF THE ACTION OF WATER UPON METALS.

By WILLIAM PITT MASON, M.D.

(Read April 19, 1907.)

Reports recording that a water contains so many parts per million of lead, zinc or other metal are common enough, but it is rare to find advance statements of what a water is capable of doing in the way of dissolving metals should opportunity be afforded it of coming in contact with them. In other words, a client who possesses a water supply which is very desirable at its source is seldom informed of the possible damage which may result thereto by reason of its being conveyed through metallic piping.

After the pipes have been laid and the water admitted to them, record is made of the result as to the metallic solvency, but little is found in the nature of a prophecy antedating the outlay of capital; which prophecy had it been uttered in time, might have had material bearing upon the investment. Again, if, as occurs in a few instances, the client be told that the water under examination is capable of acting upon certain metals, he is not given the information in such quantitative form as will enable him to make comparisons between it and other waters with reference to this property.

It is well known that all waters do not equally possess the power to attack metals and it is proper to ask that, granting such power to exist, how far is its exercise objectionable from a sanitary point of view; or, to state it differently, what amount of metallic salts in solution may be allowed with safety?

The interesting case is given of "A water from the tail-race of a gold and silver mill which showed the presence of 350 parts of lead, 51 parts of copper and 1666 parts of arsenic oxide per million of water. This water, which was supposed to have caused the death of a number of cattle, was so highly charged with arsenic

that an ordinary drink for man or beast would contain sufficient to kill."[1]

Such a special instance, however, does not come within the limits of the present inquiry.

Let us consider for a moment the question of "plumbism" or lead poisoning, as it is ordinarily presented under the classification of a water-borne disease.

The Massachusetts State Board of Health enumerates the symptoms of lead poisoning as some or all of the following: Anæmia, constipation, indigestion, loss of appetite, thirst, metallic taste, abdominal pain, colic, "drop wrist," blue line at margin of gums, lead in the urine.[2]

Dr. Hunter describing the effects of the epidemic at Pudsey, says: "Anæmia and debility were the most common symptoms. Patients nearly always complained that they felt as if they would sink down from weakness, and that the least exertion would make them sweat freely. The majority had the blue gum-line so characteristic of lead poisoning. Colic was a common symptom. Paralysis was not common, but there were five or six cases of almost general paralysis and in these cases drop-wrist was included. The amount of lead found in the waters producing these effects varied from .01 to 1 grain or more per imperial gallon (.143 to 14.3 per million)."[3]

There is some difference of opinion among the authorities as to the amount of contained lead required to condemn a water, but all are agreed that even small quantities should be narrowly watched. Thus, the Massachusetts reports note that one-half part per million has caused serious injury.[4] Haines holds that .1 grain per U. S. gallon (1.71 per million) should cause a water to be rejected.[5]

Whitelegge believes that "No water should be used for drinking which contains more than one part of lead per million, and any trace, however minute, indicates danger." (Hygiene and Public Health.)

[1] Utah Agr. Expt. Sta. Bull. 81, p. 199.
[2] Report of Mass. State Board of Health, 1898, XXXIII.
[3] Thresh, "Examination of Water," p. 88.
[4] Mass. State Board of Health, 1898, XXXII.
[5] *J. Fk. Inst.*, Nov., 1890.

To quote Dr. Summerville in his recent paper in *Water*. "Lead to the extent of .25 part per million is sufficient to condemn a potable water."

That sundry waters contain enough lead to prevent their acceptance by at least some of the standards above laid down is shown by the fact that a few years ago it was reported that sixty three (63) cities of Massachusetts possessed public water supplies which contained lead in amounts varying from 85.46 to .023 per million. In four of these cities where lead poisoning was pronounced the average amount of the metal present during ordinary daytime use was one part or over per million. Occasional instances of "plumbism" were noticed in other towns and doubtless mild or unrecognized cases occurred elsewhere.[1]

In the 31st annual report of the London local Government Board (1901 and 1902 Supplement on Lead Poisoning and Water Supply, Vol. 2, page 426), peaty moorland waters are shown to be especially plumbo-solvent, to a degree chiefly governed by the amount of acidity present, and experiments show that such acidity is due, at least in part, to acid-forming bacteria residing in the peat.

For instance, the influence of acidity is shown by the action of the following moorland waters from Lancashire and Yorkshire:

Acidity of water in terms of c c. of N/10 Na_2CO_3 required to neutralize 100 c.c. of the water.	Milligrams of Pb. in 100 c.c. of the water after filtering through lead shot.
0.2	.28
.3	.25
.4	.4
.5	.66
.6	.92
.8	1.5
.9	2.4
1.1	3.2
2.2	8.6

The London report already quoted is so firm in its belief that the cause of plumbo-solvency has been located that it ventures to rate moorland waters as "safe" if they are neutral to lacmoid and as "dangerous" if they react acid with that indicator. Attention

[1] Mass. State Board of Health, 1898, p. 543.
[2] Thresh, "Examination of Water," p. 186.

is also called therein to the fact that moorland streams are highest in acidity during wet weather because of drainage from peaty surface sources and less so during periods of no rain on account of their supply at such seasons coming from the flow of springs.

In this connection it may be noted that H. W. Clark observed that carbonic acid in a soft water was the main factor that caused lead to be taken into solution by the waters of Massachusetts.[1]

It is by no means new to distinguish between the "solution" of lead and that "erosion" of the metal which some waters exercise whereby insoluble lead salts are formed with appreciable increase in the turbidity of the water.

Such classification of the action upon lead has been developed by the report of the London Local Government Board with great care.

For our purposes it will suffice to note that "erosion" does not occur in the absence of oxygen, and we are also to remember that from the sanitarian's point of view "erosion" may be fully as objectionable as "solution" if no opportunity for clarification be furnished. In fact, the former may readily be the greater evil of the two, because of its involving the possibility of the ingestion of large quantities of lead salts held in suspension.

Piping water in tubes of galvanized iron is very common, and as zinc is often more easily attacked than lead it is pertinent to ask if it be equally dangerous. So far as our present experience can guide us towards a correct solution of this question, the reply must be a negative one and the following opinions are presented in support of such contention:

In the journal of the German Society of Gas and Water Engineers for 1887 H. Bante collected statistics to show "that the use of galvanized pipes should be in no way detrimental to health."

Similar views are entertained by V. Ehmann, director of the water supply of Wurtemberg.[2]

According to Thresh[3] "There is no doubt that waters containing traces of zinc are used continuously for long periods without

[1] *Engineering News*, Dec. 1, 1904.
[2] *J. Fk. Inst.*, Nov., 1890.
[3] Examination of Waters and Water Supplies, p. 85.

causing any obvious ill effects. The water supply to a small hospital with which I was connected for some years always contained a trace of zinc, probably never more than half a grain of the carbonate per imperial gallon (7.1 parts per million), but I never observed any indications of its being deleterious, although such effects were looked for."

In the Massachusetts Board of Health report for 1900, page 495, the following table is given showing amounts of zinc in sundry public supplies, the metal having been dissolved from pipes of galvanized iron or brass during ordinary use. The results are averages and are in part per million.

West Berlin	18.46
Milbury	3.08
Newton	1.25
Marblehead	0.85
Grafton	0.73
Wellesley	0.68
Fairhaven	0.52
Lowell	0.33
Webster	0.28
Sheffield	8.65
Palmer	2.90
Beverly	2.71
Fall River	0.07

The first of the above, West Berlin, drew its water through four thousand feet of galvanized iron pipes. The quantity of metal dissolved therefrom was certainly large but appears to have produced no evil results. "As far as is known the amount of zinc present in these waters as used is not sufficient to have any effect upon the health of the consumers of the water."

"The Board has investigated the question of the presence of zinc in drinking water supplies where galvanized iron pipes are used and, except in case of the use of some ground waters, containing very large amounts of free carbonic acid, which dissolves zinc and many other metals very freely, the amount of zinc found in ordinary water supplies, where galvanized pipes are used, is not sufficient, in the opinion of the Board to give anxiety."[1]

[1] Massachusetts Board of Health, 1902, XLIII.

In a private letter of more recent date the president of the above mentioned board says: "If there had been any harmful effects of the presence of zinc in the public drinking waters of the state that fact would have undoubtedly been brought to our attention. No statement to this effect has been made, nor has there seemed to this board reason suspecting serious danger from this source."

As an instance of long continued use of a water containing much zinc, the case of Brisbane, Queensland, should be quoted. In that city rainwater tanks built of galvanized iron are found in all the houses. The water, which is in common use, contains about 17.1 parts per million of zinc, yet no harmful effects have been observed.[1]

In his experience the writer has been unable to trace any evil effect due to the presence of zinc in drinking water, even when the quantity rose as high as 23 parts per million in a water which is in constant use. It might be well to add, that in the particular case just cited the zinc was derived from a long stretch of galvanized iron pipes and the amount of the metal present was subject to great and frequent fluctuations for reasons that were not apparent.

It must be admitted however, that, even on the assumption that the presence of zinc in a water is of no sanitary significance, its being there is nevertheless not desirable, and the probability of a supply being able to dissolve it should be determined and reported.

What can now be said with reference to some convenient and standard method of reporting the possible action of water upon any of the common metals?

The suggestion offered is this:—Let the action, whether solution or erosion, be stated in parts per million, and let it be that of one litre of water acting upon one square decimeter of bright metal for one hour at 15° Centigrade.

The mode of procedure followed by the writer is to submerge a piece of bright sheet metal, one decimeter square in two liters of water contained in a wide-mouthed bottle. The water is oc-

[1] Hazen, *Eng. News*, April 4, 1907.

casionally given a gentle motion and is kept at 15 degrees for one hour, after which time the metal in solution or suspension is determined. One hour is sufficient time to allow of the watching of metallic solvency, and let it be added, the limiting of the time of action to the standard period is important, for the rate of action of the same water is not only variable but the ratio of the total action during different lengths of time is not a simple one. Thus, the quantity of metal attacked in ten hours is by no means ten times that acted upon during one hour.

In conclusion, let it be said that although we know in a general way that softness, acidity, dissolved gases and the presence of much chloride or nitrate will tend towards metallic action, while alkalinity and hardness are rated as protective agents, yet it is far better to actually test a water with reference to its behavior towards metals than to attempt any prophecy of its action based upon analytical knowledge of what the water may contain.

TROY, N. Y.

PRODUCTION OF SYNTHETIC ALCOHOL.

By H. W. WILEY and HERMAN SCHREIBER.

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(Read April 20, 1907.)

When Faraday and Hennell[1] discovered that ethylene would combine with sulfuric acid, forming ethyl sulphate, a new opportunity was given for the quest of new compounds derived therefrom. The whole subsequent history of synthetic alcohol is a mass of methods and contradictions of them. Fritzsche[2] claims that Hennell[3] first demonstrated the identity of the alcohol, made by diluting ethyl sulfate with water and distilling off the alcohol, which is plain from the above reference, while others claim that Berthelot first made this observation. Berthelot[4] did produce alcohol from ethyl sulfate and being engaged in investigating coal gas which was known to contain ethylene he proposed that alcohol could be made from the ethylene in coal gas, but his efforts in this direction did not make its utilization appear of commercial value. However, the alcohol fever had gained a strong hold on the people, which finally lead to the offering of stock in a concern whose object was the manufacture of ethyl alcohol from coal.[5] Cotelle, the promoter of this scheme, claimed to produce one hectoliter for 23 francs.[6] Fritzsche[7] states that it is doubtful that any commercial attempt was made. The chief difficulty in producing alcohol from the ethylene in coal gas at this time seemed to be the cost of reconcentrating the sulfuric acid resulting from the diluting and distilling of the ethyl sulfate. But Fritzsche claims that the enormous dilution then practiced (5–6 parts water to 1 ethyl sulfate) is not necessary and that

[1] Gmelin Krauts, "Handbook," Vol. 4, p. 721.
[2] *Chem. Ind.*, 1897, Vol. 20, p. 266.
[3] *Philosophical Trans.* 1828 p. 365.
[4] *Comptes rend.*, Vol. 40, p. 102.
[5] Wagner's "Jahresbericht," 1863, p. 469.
[6] *Chem. Ind.*, 1897, 266.
[7] *Chem. Ind.*, 1897, 266.

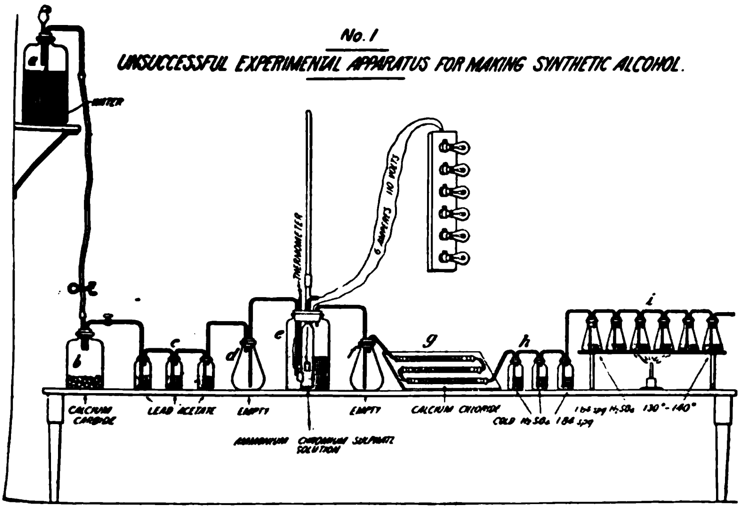
dilution with an equal weight of water will give nearly the entire ethyl content as alcohol. He estimates that 95,000 hectoliters alcohol could be produced from the coal gas which is annually produced in Germany. As we do not know that alcohol is at present produced from coal gas we suppose that there are still difficulties which prevent it.

The matter has not yet lost all its interest and appears occasionally even in economic guise. Since the commercial production of calcium carbide much interest has centered in the possibility of building alcohol from it. Frazee[1] gives four possible methods of building alcohol from acetylene. The first consists in passing hydrogen and acetylene over platinum black and so gaining ethylene according to the equation $C_2H_2 + 2H = C_2H_4$ then absorbing the ethylene in sulfuric acid, diluting the ethyl sulfate and distilling off alcohol, $C_2H_4 + H_2SO_4 = C_2H_5HSO_4 : C_2H_5HSO_4 + H_2O = C_2H_5OH + H_2SO_4$. This method was not tried as Wilde[2] states that if hydrogen and acetylene are passed over platinum black ethane is formed and no ethylene. Frazee's second possibility is to build ethane from acetylene then make the chlorine substitution product (ethyl chlorid) and saponify this with KOH. This method would undoubtedly give alcohol but in a round about way. His third method is the building of acetaldehyde from acetylene and reduction to alcohol. This method is the best of the four which he gives and was the one by which we were finally able to make alcohol. His fourth method is the ethylene iodide method which consists in absorbing acetylene in hydriodic acid, oxidizing the ethylene iodide to acetaldehyde by means of lead oxid and then reducing the acetaldehyde to alcohol. This method has been found very difficult by Krüger and Pückert[3] and was not tried by us.

Of all the methods found by us, the one given in *The Electrical Review* (for 1899, page 375) seemed the simplest and most direct. Here the acetylene is absorbed by a solution of chromium ammonium sulfate in which hydrogen is generated electrolytically which converts the acetylene to ethylene. This ethylene passing out of the

[1] *Iowa Academy of Science*, 1904, Vol. XII., p. 179.
[2] *Berichte*, 7, 1874, p. 353.
[3] *Chem. Ind.*, 18, 1895, p. 454.

solution is absorbed by strong sulfuric acid and forms ethyl sulfate from which alcohol is made by dilution and distillation. Apparatus No. 1 was constructed to carry out this scheme. The acteylene was generated in a two-quart Mason fruit jar (*b*). Water was fed into this jar by means of a bottle (*a*) elevated so that water siphoned from it would have a fall of six feet. The exit of the acetylene was regulated by a glass valve. The gas then passed through 3 bottles (*c*) containing lead acetate to take out sulfides, then through an empty flask (*d*) which was to take care of back pressure and then into the electrolytic cell (*e*) to be absorbed and regenerated as



ethylene, from here it passed an empty flask (*f*) to catch water which the gas might carry mechanically, then through three sixteen inch glass tubes (*g*) filled with calcium chloride, then three bottles (*h*) containing strong sulfuric acid (cold) to dry as thoroughly as possible and then into six flasks (*i*) containing strong sulfuric acid which was heated to 130° to 140° C. by means of a bunsen burner under the sand bath on which they stood. The current was modified by passing 6 32-c. p. lamps so that it was cut down to 6 amperes at 110 volts. This gave approximately 3 liters of hydrogen per hour and the flow of acetylene was so regulated that the quantity passing should be about 2½ liters per hour, or about 10 times

the weight of the passing hydrogen. The chromium ammonium sulfate was made acid by 10 cc. of concentrated sulfuric acid to prevent deposition on the electrodes and was kept at a temperature approximately 40° C. as directed in the method. If the six bottles (containing strong sulfuric acid) intended to absorb the ethylene were kept cold they remained colorless but if heated they became brown, then black, and finally were thick in consistency. On diluting with water and distilling this material foamed and bumped violently so that it was impossible to distil it even on great dilution if the absorption had been carried on for several days. The process was therefore run only a few days from 1–3. The sulfuric acid was then diluted and distilled. The distillate smelled strongly of sulfurous acid and somewhat of aldehyde and gave the iodoform reaction but no alcohol could be isolated by fractionation. The contents of the three bottles containing cold sulfuric acid (which was brown also) was diluted and distilled. The distillate smelled strongly of aldehyde, gave the iodoform test and formed resins with alkali but alcohol could not be fractionated from it. The process was varied by removing the calcium chloride tubes and also by not heating the sulfuric acid, but alcohol was not obtained.

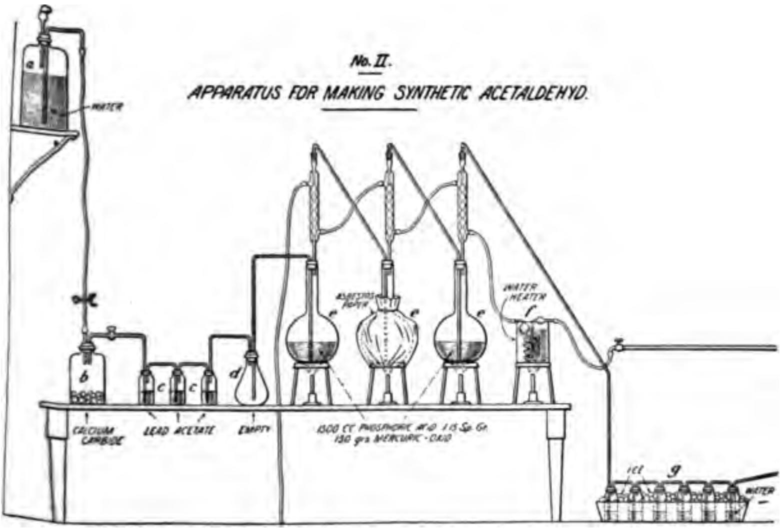
Beilstein[1] states that ethylene is produced when ammonia reacts on a mixture of zinc dust and copper acetylide. Wood[2] says that he was unable to make any alcohol when he used this method for producing ethylene. Due to the excitable temper of copper acetylide this method was put off to be tried only as a last resort and as we reached the desired end by another method, was not tried at all.

The aldehyde method was another possible way of procedure. But here again the literature is decidedly contradictory. Lagermark and Eltekow[3] state that acetylene treated with sulfuric acid sp. gr. 1.35 (45–46%) and then distilled gives crotonaldehyde. Erdmann and Kothner[4] state that acetylene passed into a hot solution containing one volume water and two volumes sulfuric acid is converted to crotonaldehyde and that acetylene passed through a mixture of

[1] "Handbuch," 3d ed., p. 128, Vol. 1.
[2] *Chem. News*, (78), 1898, p. 308.
[3] *Berichte*, 10, 637.
[4] *Zeit. Anorg. Chem.*, 18, 1898, p. 55.

three volumes of sulfuric acid and seven volumes water is converted to acetaldehyde or that approximately 75 per cent. sulfuric acid gives crotonaldehyde, and 42 per cent, sulfuric acid gives acetaldehyde. These figures assume that Erdmann and Kothner mean H_2SO_4 1.84 sp. gr. when they say "concentrated." The latter also find that addition of mercuric oxid facilitates the process and that phosphoric acid of sp. gr. 1. 15 may be used, which they claim gives a purer acetaldehyde than sulfuric acid.

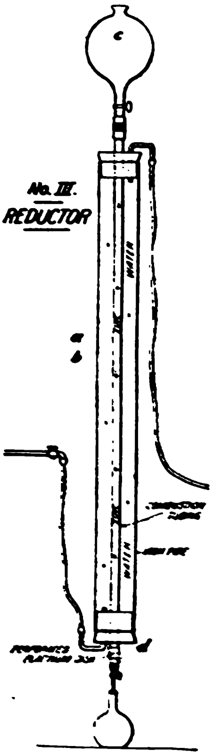
Apparatus No. 2 was constructed to carry out Erdmann and Kothner's method. The acetylene was again generated in a fruit jar (*b*) and washed through lead acetate[1] (*c*) then through an empty flask (*d*) to catch any liquid forced back by back pressure. From here it passed through 3 round bottom Jena flasks (*e*) (3 liter) containing 1500 c.c. sulfuric acid (3 volumes acid, 7 volumes water) and 100 grams mercuric oxid. To prevent bumping, glass beads were put in the flasks and the flasks wound with asbestos paper. The



flasks rested on shallow sand baths heated by a bunsen burner. Each flask was closed by a rubber stopper carrying a reflux condenser for exit and a $\frac{3}{16}$-inch glass tube reaching to the bottom of the flask for entry of gas. The reflux condensers were fed by warm water

[1] "Lehrbuch der anor. Chem.," Erdmann, 4th ed., p. 437.

from (*f*) to prevent the condensation of aldehyde as much as possible. However, the solutions soon became dark and the mercury was reduced to the metallic state where strong acid was used. The gas was run through three conversion flasks with the idea that the yield of aldehyde would be greater. The gas was now treated in various ways, sometimes washed through cold water (*g*) and sometimes through ammonia or sodium bisulfite. The latter ways were abandoned as the aldehyde in a solution of ammonia or bisulfite is resinified on standing. Attempts to reduce the aqueous aldehyde by means of sodium amalgam were unsuccessful as our method of manipulation was faulty, and not according to the one devised by Wurtz.[1]



The reduction of pure acetaldehyde (Kahlbaum) by passing it over palladium (precipitated on asbestos) together with hydrogen was tried but without success. Various temperatures from 20° to 400° C. were used in these experiments. Acetic acid[2] and zinc were not tried as the evolution of hydrogen is slow and acetaldehyde is very volatile. Acetaldehyde was diluted and attempts made to reduce it by sulfuric acid and zinc but without success as the evolution of hydrogen is slow and the process was not carried on long enough. Apparatus No. 3, a Jones reductor, was now erected consisting of a piece of combustion tubing (*b*) five feet long encased in a large gas pipe (*a*) by means of rubber stoppers and cold water circulated between the two. A separatory funnel (*c*) was attached to the top of the combustion tubing by means of a rubber tube and a small perforated platinum disk formed the bottom of the tube which was extended beyond the disk by a three inch piece of the same glass tubing (*d*) to allow the insertion of a rubber stopper carrying a glass stopcock so that the reductor could be regulated

[1] Wurtz, *Liebigs-Annalen*, 123, p. 140.
[2] *Berichte*, 10, 1717 Krafft.

if necessary. The inner tube contained commercial zinc (mossy). About 25 cc. pure aldehyde were mixed with one liter dilute hydrochloric acid (four volumes acid 1.20 sp. gr. to six volumes water) and passed through the reductor until the evolution of hydrogen was very small. The zinc was then precipitated out of the resulting liquid by sodium carbonate to prevent bumping during distillation. The zinc being filtered off the filtrate was distilled. The distillate was made alkaline with caustic potash and silver nitrate added to oxidize aldehyde and after standing over night the silver was filtered off and the filtrate fractionated. The last distillation was made from an oil bath, a side necked test-tube being used as a retort. The liquid was allowed to stand over anhydrous copper sulfate before this distillation. In this way a fraction was obtained which boiled at 78°–78.7° C. and had the odor and taste of ethyl alcohol.

Trials were also made with the reductor using zinc amalgam and sulfuric acid, and zinc amalgam and hydrochloric acid, and then using zinc and sulfuric acid, and at last zinc and hydrochloric acid which proved best. The reductor was adopted in preference to making the reduction in a bottle as the liquid in passing over the zinc was thought to give more intimate contact between the acid, aldehyde and zinc than could be obtained by means of a bottle. Aldehyde was now made by the Erdmann-Kothner method by means of apparatus No. 2. The converters were charged with 1500 cc. phosphoric acid sp. gr. 1.15 and 150 grams mercuric oxid. The aqueous aldehyde obtained by running the apparatus 14 hours was mixed with 2 liters dilute hydrochloric acid (4 volumes acid to 6 volumes water) and the mixture passed through the reductor (apparatus No. 3) after reducing the zinc was precipitated and filtered out, the filtrate distilled and the aldehyde oxidized by silver nitrate, the filtrate from the precipitated silver was fractionated and a small fraction was obtained whose boiling point was 77.5°–78.9° C. and which had the characteristic taste and odor of alcohol.

THE PROGRESS OF THE ISTHMIAN CANAL.

By ELIHU THOMSON.

(*Read April 19, 1907.*)

It was the privilege of the writer to be one of a party which visited the Canal Zone, as it is termed, on March 1 and 2 last. The expedition was organized for an inspection of the conditions and progress of the work there going on. In view of the conflicting accounts which from time to time had been published, plans for a visit and personal inspection of the actual conditions were matured last fall.

The party was composed of about ninety men, members of the Commercial Clubs of Boston, Chicago, Cincinnati and St. Louis, many of whom are at the head of large enterprises of varied character in the cities mentioned; often closely connected with public activities. There were presidents and other officers of railway, express, power and other public service corporations, managers of mills and varied manufacturers, heads of commercial enterprises, banking institutions, fire insurance, and a few professional men such as lawyers and engineers. The mayor of the city of St. Louis and ex-Governor Francis, the president of the Louisiana Purchase Exposition were of the party.

A steamer of the Hamburg-American Line, specially fitted up for travel in the tropics, and chartered for the trip, sailed from New York on February 18 with about twenty passengers, mainly the Boston contingent, and reached Charleston, S. C., two days later, where the members from the western cities embarked. After a direct run to the island of St. Thomas, of the Danish West Indies, and a brief visit to Porto Rico, the ship left the southern port of the island, Ponce, for Colon. During the run about nine hundred miles southwesterly from Porto Rico, much time was given to securing an effective organization of the passengers, so as to obtain as much information as possible in a short time. To this end there were formed eight committees each composed of from ten to twelve

men. Specific subjects were selected, one for each committee, subjects which related to the sanitation, plan of administration, food and commissary work, housing, social and labor conditions, effects of climate on Americans, efficiency of plant and progress of work. Those serving on any particular committee were chosen in accordance with their special aptitude or training in the subjects with which it was to deal. The chairmanship of one of these divisions was entrusted to the present writer. Before the arrival at Colon, the organization was in good working shape, and in some instances, to assist the work, a further division into sub-committees was made.

Wireless communication with Colon permitted requests to be forwarded to the effect that upon the arrival there, the canal officials in charge of the particular phases of the work might meet the respective committees prepared to furnish such information as might be sought by them. To render this effective, the committee had, beforehand, formulated a scheme of inquiry to be followed if possible, upon arrival at the Canal Zone.

In the special message of the President to Congress on December 17, 1906, concerning the Panama Canal, which followed upon his personal visit to the isthmus, he referred to the expected visit of the commercial clubs, and promised that every facility would be given them "to see all that is to be seen in the work which the government is doing." He says further: "Such interest as a visit like this would indicate, will have a good effect upon the men who are doing the work, on one hand, while, on the other, it will offer as witnesses of the exact conditions men whose experience as business men, and whose impartiality, will make the result of their observations of value to the country as a whole."

The journey from Porto Rico to Colon was through the comparatively calm and warm tropical sea, swarming with flying fish, which rose in flocks as the steamer moved among them. The weather conditions were good, and the temperature of the air, both night and day, owing to the prevalent trade winds, was not warm enough to cause any discomfort. A special train on the Panama Railroad had been arranged for to meet the body on its arrival at Colon, which took place on the morning of March 1. Each car

of this train on the journey across the isthmus, was occupied by two of the committees, eight in all, and with them were the officials of the Canal Zone having special charge of the subjects upon which the particular committee was to seek information. It is fair to say that this was in all cases given freely and courteously with the utmost frankness, calculated to elicit the fullest interest and sympathy.

After leaving Colon on the trip southeasterly to Panama, a number of stops were made at various points along the route of the canal. At Christobal near Colon an inspection of docks, machine shops and other shops for repair and construction, was made. Here the equipment was found to be modern and well adapted to the work, and there seemed to be a good force of skilled machinists and other workmen, among whom were many Swedes. Similar large shops exist at other points, notably at Empire not far from Culebra.

The working forces seemed to be in excellent physical condition. From Christobal there runs for several miles the canal dredged by the French. Owing to change of location this does not become part of the accepted plans, and will be used only for transporting materials and machinery to the vicinity of Gatun, about seven miles from Colon, the site of the proposed great dam known as the Gatun dam. Leaving the train at this point the hill at the east end of the proposed dam was climbed and the site of the great canal locks to be constructed here was reached. The weather conditions were so good that even in the tropical sun no discomfort was experienced even in briskly walking up hill. This was due to the cool trade wind coming from the east.

From the Gatun Hills, looking across to the farther hills where the other end of the dam will rest, one begins to acquire an impressive sense of the magnitude of the whole enterprise, such as no amount of reading or examination of maps or plans can give. Here several large steam shovels, and construction trains were actively in service, excavating at the lock sites and building part of the embankment of the dam itself.

There has been much discussion of the subject of a canal with locks as against a true sea-level waterway, the latter project being

favored by many of the foreign engineers, while the decision of Congress to build a lock canal was made, as is well known, in accordance with the recommendation of the American engineers. The writer does not profess to be able to judge between these two schemes. It would be presumption for one who, though much of his work has been engineering of a special kind, is not experienced in civil engineering, much less in such matters as have divided the opinions of many of the foremost engineers of the time, who have been called upon to devote a long period to their consideration. All that is attempted to be recorded here is an impression; which may not be worth much. Still it is an impression. The writer had previously in common with many others, conceived the idea that it would be a mistake to build any other than a sea-level canal, but upon arriving at the site of the Gatun dam, and witnessing the conditions, this idea soon gave place to a feeling that the lock canal project was probably a correct solution. Nothing has since been learned tending to change this impression, which, in fact, was more and more confirmed or strengthened as the further inspection of the work in the zone was pursued.

The problem of the Chagres River floods which was so serious in the case of a sea-level canal solves itself in the lock canal, with the dam at Gatun. This structure when completed will impound the river water even in heavy floods and form above the dam a great fresh-water lake of about one hundred and ten square miles in area, the level of which will be about 85 feet above the sea. For about twenty miles ships will be able to steam at good speed in this elevated lake and make up for time lost in passing the locks, so that the actual time of passage through the canal may not differ greatly from that which would have been needed in the case of a sea-level construction. On the right of the proposed dam, as one faces Colon, was seen the site of the three great locks, which will be built in flight and in duplicate. In fact, the work of excavating for them had been begun, as before stated. The locks being in duplicate will permit simultaneous passage of ships both ways, or up and down. They will be of size enough to accommodate, with considerable margin, the largest vessels in existence; greatest length, breadth of beam and draught.

The dam itself is to be in reality a great earth bank spanning a distance of about 7,700 feet between the hills, and it will be not less than 2,600 feet wide at its base, tapering to a crest of about 100 feet wide and this crest will be considerably over 100 feet above sea level, with a great concrete spillway near its center. At the site of the dam, careful rock soundings have been made, a work which was still going on, and samples brought up from various depths were examined. These show that at distances from the present surface of the ground, varying from a few inches to 200 feet or more, a solid compact rock, called indurated clay, sometimes including fossil marine shells, exist; slaty gray in color. The engineers seem so far to be satisfied with the nature of the foundation on which the great dam will rest, in view of its great width at the base, which is regarded as giving ample stability.

The material required for the construction of the dam will be largely that brought down from the heavy cutting at Obispo and Culebra, though at the time of the visit of the writer, none of this was being used at the dam, as the transportation facilities had not been completely arranged. The problem is one of transportation and the conditions will be much improved when the double tracking of the Panama Railroad is completed. This with the exception of nine miles, had already been done. Besides this, many large modern locomotives and construction cars are soon to be added to the plant, already so extensive. In the meantime, some of the small capacity dumping cars left by the French Company are being used, as are also some of the numerous small French locomotives, found along the line. The parts of some twenty-five or thirty new locomotives were seen on flat cars, awaiting assembly at the shops in the zone.

Leaving Gatun, the railroad follows up the Chagres River at a varying distance therefrom, through a country which is at first but slightly hilly, but which becomes more and more rolling. It is for the most part covered with a thick growth of tropical jungle, with some cleared spaces. Here and there along the route are small groups of huts or shacks inhabited by negroes; remains of a mode of life which will gradually be eliminated from the zone. Often the views from the train are most picturesque, as river vistas and

stretches of country come into view bordered or covered by the bold and intensely colored foliage of tropical plants. At last the river valley leads off to the east and the train moves toward the beginnings of the deep cutting at the divide.

At Bas Obispo over thirty miles from Colon is the great rock cut and since the general course of the canal is southeast, this cut is about five miles to the northwest of the celebrated Culebra cut, where the greater part of the excavating work needed is now done and has still to be done in the future. From the Gatun dam there will be about thirteen miles of flooded river valley deep enough for ships of the greatest draught without dredging or excavation, but for the rest of the distance toward Bas Obispo material in increasing depth will need to be removed.

The French left the level of the cut at Bas Obispo at about 100 feet elevation, which has since been cut down by the Americans to 74 feet up to March 1. To satisfy the condition of an 85-foot water level some thirty-four feet more in depth will be removed. The deepest cutting done and yet to be done, is at the true divide or Culebra cut. At Bas Obispo, but more especially at Culebra, are the evidences of the great amount of work which had already been done by the French. In fact, the real work of building the canal is here. To complete this section of the canal, a length of about nine and one half miles, will require the removal of about 50,000,000 of cubic yards of rock and earth in addition to that which has been taken out hitherto. At the station called Empire, between Bas Obispo and Culebra, a stop was made for viewing the shops located there, and to allow a glimpse of some of the discarded French machinery to be had. Here rows of beautifully built, but according to present standards, small-sized locomotives of French make are found partly overgrown with vines. The workmanship of these and other remains of French plant, so bountifully strewing the canal route, is highly esteemed by the present engineers. The fault of small size or capacity, it is only just to say, would have characterized such machinery in general at a time twenty or more years beck. A considerable number of these French engines are actually in service now. Their refined construction is sufficiently indicated by the fact that they have copper fire boxes and white metal fire tubes.

On the way from Bas Obispo to Culebra the evidences of great activity were numerous. Stone cruchers, roundhouses, coal chutes, air compressing plants for drills and the present dumping grounds were seen in succession. Camp Elliott, with a body of U. S. marines, the auditing and disbursing officers of the Isthmian Canal Commission, the Circuit Court District No. 2, the officers of the engineer of the Culebra Division, etc., were passed.

Near the great Culebra cut was found the apparently flourishing town of Culebra. Here are situated the administration offices and the headquarters of the chief engineer, Mr. John F. Stevens, who here joined the visiting party. The great Culebra cut was seen; not very different in aspect from the time when the task was given up by the French company. Here as at Bas Obispo, work was in active progress, huge steam shovels being used, some of which were capable of lifting at one time as much as five cubic yards of broken rock or earth, after it had been loosened by explosives, and depositing it upon the construction cars in long trains, in which it was hauled away and dumped. The tracks on the dumping grounds, as well as in the area of excavation, are required to be quickly moved or relocated; a necessity which has led to the devising, by one of the engineers, of a plan for quickly shifting portions of the line sideways to a distance of nine feet without disjointing it or loosening it from the ties. The town of Culebra, like the other settlements in the zone, is remarkably clean. Much care has been given to the proper placing and construction of the buildings. Here in a large hotel restaurant the visiting party partook of a midday meal which was well prepared and served. There was no annoyance from flies, mosquitoes, or other insect pests. In fact, the writer believes it to have been the general experience that no mosquitoes were encountered anywhere in the Canal Zone. It may possibly have been the season when they are naturally scarce or absent, or the absence may have been due to preventive measures. While traversing the Culebra cut in flat cars provided with improvised seats or benches, men belonging to the mosquito brigade were noticed sprinkling oil on small pools or sluggish streams within the cut. The sanitation of the zone will, however, be alluded to further on.

Within the Culebra cut the highest point of the divide is now about 167 feet above sea level, having been originally or before any cut was made about 333 feet. The French cut down 160 feet. At this point the additional cutting required to complete the canal is about 127 feet. A total depth of cut of about 290 feet will thus be needed. A sea level canal would have made this 375 feet. Naturally the amount of earth to be removed increases with the depth because the greater depth requires much wider cutting to provide reasonable slopes safe from landslips, and the length of the excavation is likewise greatly extended. The money expenditure for the sea level project as well as the time needed would have been several fold more than for the lock or present plan.

Explosives are used both in the rock at Obispo and in the compact earth at Culebra and in January last, it is reported, about eleven miles in total length of holes were drilled for blasting. Beyond Culebra the site of the first lock on the Pacific side, which is known as the Pedro Miguel lock, was soon reached. It is to be a duplicate lock with a single drop from the 85-foot level, of about thirty feet or a little less.

At its foot another fresh-water lake at 55 feet above sea-level will be made by dams at a place called La Boca, about two miles from the city of Panama and to the west thereof. The area of this lake will be upwards of ten square miles. Alongside of the La Boca dam will be located the Sosa locks at Sosa hill. These will be in duplicate and in a flight of two with level differences of about 27 feet or more, or 55 feet for the two locks. Inasmuch, however, as the maximum tides at Panama are as great as 24 feet, provision for variation in the lock levels is made in accordance therewith. At Colon the tides are a little more than 2 feet. From the foot of these locks at Sosa a channel is to be dredged straight out to sea in the Bay of Panama, the locks at Gatun being similarly reached from the Atlantic side by a straight channel out to sea in Limon Bay, upon which bay Colon is situated. Practically none of this work of dredging is yet done.

Since the present plans follow a different route from that adopted by the French, the dredging accomplished by them in not now of use. The city of Panama is about two miles to the east of the

new location of the sea channel from the Sosa locks or La Boca Dam, and it is just outside the ceded territory known as the Canal Zone. It has, however, recently been given clean and well-paved streets. It possesses much of the picturesqueness of the old Spanish settlements.

On the edge of the zone at Panama, the United States government has built a large modern hotel, suited in construction to the tropics. It is on an elevated site overlooking the city and the Bay of Panama. This hotel is used by officials and engineers of the Canal Zone and their families. Here at the Tivoli, as it is called, an evening reception and dinner was tendered to the administrative force engaged in the zone by the party of visitors, at which were present the President of the Republic of Panama, the U. S. Minister to Panama, the Chief Engineer, Mr. Stevens, and others. Although Panama is but nine degrees north of the equator, the weather was all that could be desired, a clear sky, a fair breeze, and moderate temperature. The full moon rose over the bay, which happens to extend eastwardly from the city, so far as to give the effect of an open sea. Thus the Pacific ocean is to the east of Panama, to all appearances. After a comfortable night at the Tivoli, a detailed inspection was made at the site of the proposed dams at La Boca and that of the locks, there. The work of construction is soon to proceed. On the return trip to Colon a stop was made for a visit of inspection to the great storehouses at Mount Hope, formerly known as Monkey Hill, a few miles from Colon. Here there can be found, properly classified and arranged and subject to requisition, supplies and equipment of nearly all kinds outside of food; an epitome of all human needs; the product of innumerable factories of the most varied description. A catalogue of the things stored here would fill volumes. Here also were seen large quantities of stores in the form of iron and steel bars and plate left over from the French regime and largely capable of utilization in the present work.

While all along the canal route there exists an immense amount of discarded machinery known as French scrap, it would not pay at present to attempt to gather it up; the transportation facilities at command being already taxed to the utmost in the legitimate work

of construction and supply. Notwithstanding this fact, a large part of the cast iron used in the foundries in the zone is taken from the French scrap. It is possible that the light rails of the railways used by the French in construction, may become available as reënforcing material for concrete to be used in locks, or the like. Doubtless in time an opportunity may arise for collecting this valuable debris, consisting usually of high grade metal.

The question of health on the Isthmus of Panama is of vital importance in the prosecution of the work. In times past, the experience of the French company in regard to the spread of disease, and in the consequent mortality, was so bad that the region became a by-word for unhealthfulness and danger to life. This was, however, before modern methods of sanitation were known or practiced; and before the modes of transmission of the germs of malaria, yellow fever and severe intestinal disorders had become known. As soon as certain species of mosquito were known to be intermediate hosts for the organisms to which malaria and yellow fever are due, the problem of canal construction was seen to be in a large degree dependent on getting rid of these culture-charged insect pests. Throughout the Canal Zone the evidences of success in this direction are palpable. Under the direction of Colonel Gorgas, who has charge of the sanitation of the zone, it has been rendered much safer than many localities in our southern states. What menace there is, is not within the zone, but arises from the possibility of introduction from the outside. A most admirable system has been put into practice, including medical inspection, distribution of medicine, drainage, fumigation, mosquito brigades and general sanitation, such as abatement of nuisances, removal of offal and garbage, clearing of land, burning of rank vegetation, etc. The whole is a splendid example of the application of scientfic principles which might well be copied in many places. The first evidences were found at Colon in the filling in of low ground, the paving of streets and improved drainage. Again at Gatun, the tropical jungle had been cleared away almost to bare ground, especially around the habitations and where men were at work. Drainage channels had also been dug. While a few tent houses were still in use there, these were soon to be replaced by a type of dwelling now usual in the

zone, and which permits excellent sanitation and protection from mosquito infection.

These buildings are of wood, well painted, supported on posts or on pillars of concrete so as to be clear of the ground. They are of one, two or three stories in height with wide piazzas on each floor, sometimes all round, securing coolness and shade. The piazzas are screened with brass wire netting and in the sleeping apartments the usual mosquito netting is a supplemental protection. The habitations are situated on high ground, as on hills or hillsides, which can readily be kept cleared and free from pools of water. Underground drainage is provided where it is conducive to the general result.

Too much praise cannot be given to the work which has already been accomplished. The present remarkable healthfulness, the fruit of this intelligent system, is seen in the low mortality disclosed by the recent records of the zone. After all, there is no more important influence to be reckoned with in the success of the construction work, than the health and vigor of the men engaged in it. Add to the measures of sanitation, the provision of proper food and good water, together with prevention of abuse of alcoholic drinks, and it would seem that the problem of labor, even white labor, on the isthmus is solved.

It is curious to note the opinion of the men in charge as to the value of the different classes of labor of which use has been, or is now made. Negro labor, largely from Jamaica and other West India islands is rated much below white labor and the pay accorded is accordingly less. White labor from northern provinces of Spain is reported as most satisfactory and Italian labor is also looked upon with favor. It was found necessary not to entrust the negro with the choice of his own diet, as this resulted in his using only watery tropical fruits, or innutritious yams, etc., rendering it impossible for him to sustain effort, owing to actual lack of nourishment. As a result, three meals are furnished at thirty cents a day and these contain a proper balance of nitrogenous and carbohydrate constituents. He is compelled in this way to receive due nourishment and

it is said that the wisdom of this arrangement is easily seen in the work accomplished.

In Colonel Gorgas's February report to the Department of Health of the Isthmian Canal Commission, in relation to the screening of houses, occur statements to show how little the efforts in their behalf are appreciated by the negro employes. He says: "Unfortunately for the colored employees, as well as for others, the metallic screening on the buildings occupied by them is roughly treated and abused by them and has to be protected and watched." Again: "The white European laborer works much harder and more continuously than the colored employee. Aside from the clerical force, the white employee is exposed to the same conditions as the colored employees. . . . The sleeping quarters of the colored laborer and those of the white laborer are similar in every respect."

The President in his message before mentioned has referred to the fact that the colored laborer after having been brought to the zone at government expense, frequently escapes from control and resolves himself into a loafer at Colon or a jungle dweller occupying unsanitary unscreened shacks. This constitutes a most undesirable element, and even a menace from the ease of propagation of disease among such a class. Hence there is an increasing tendency to utilize desirable white labor in greater amount, and this may eventually result in a much increased proportion of whites to blacks in the zone, a proportion which has been approximately one to four hitherto.

Concerning the actual work of canal construction already accomplished under the present regime it may be said that only within the past few months has a real beginning been made. There was needed a season of preparation, arranging for sanitation, organizing the working forces, constructing buildings, storehouses, gathering supplies, and machinery. This period may now be said to have been succeeded by the opening of another one to be devoted to the shifting of huge volumes of earth and rock; the real construction period, the work accomplished in which depends directly on the maintenance of the conditions which have been so far established, and the large cost of which should be balanced by the reduction of time and expense for the actual construction of the canal proper.

There were, on March 1, according to information, between 25,000 and 30,000 men at work on the isthmus and the amount of material removed in cubic yards in the month preceding had been exceeded, so that it was thought that the figure of 1,000,000 cubic yards per month could soon be maintained.

The work itself was found to be proceeding steadily, backed by energy and earnestness of purpose of the men who were in charge. The general impression gained by the visiting body was that, with an organization such as existed under Mr. Stevens and with the improved living conditions enabling suitable labor to be secured and retained, and with modern machinery of great capacity, the progress in building the canal can be expected to continue steadily and perhaps further improvements in detail will be made. Everything depends upon maintaining an efficient organization which shall preserve the high working standard which has done so much within the past year. There is need of rational diversion and entertainment for the men employed. Schools have already been established for the children of the settlements, and it is believed are under the care of competent teachers. Athletic exercises and games, such as baseball, are resorted to for amusement and the climate is not such as to forbid moderate exertion out of doors even as pastime. While the annual rainfall at Colon is very high, ranging upto about 140 inches per annum, at Panama on the other hand it is said to be only about one third as great or about what we have along the Atlantic seaboard.

On leaving Colon for the return journey, the eight committees before referred to, utilized some of the time in preparing reports which were submitted for discussion to the whole body at meetings held for that purpose. The final result was the preparation and adoption of a combined report commending the work witnessed at the zone and the conditions which rendered it possible.

It may be too early to make predictions, for there may arise at any time serious obstacles and setbacks, but if conditions continue as favorable as they now appear to be, the completion of the great work, so important especially to the United States, should be possible within eight or at most ten years. The result of the inspec-

tion by the organized body of ninety members of the Commercial Club party is in reality an endorsement of the work of the Isthmian Canal Commission and a corroboration of the President's report to Congress after his memorable visit to the isthmus and remarkable practical examination of the work. It is a work in which every citizen should feel an interest.

THE ASSOCIATION THEORY OF SOLUTIONS.

By WILLIAM FRANCIS MAGIE.

(*Read April 19, 1907.*)

When it was discovered, by van't Hoff, that the osmotic pressure of solutions obeys the laws of gases, the conclusion was drawn, in many quarters, that the osmotic pressure is to be explained as a pressure arising from the impacts of the dissolved molecules or ions against the bounding surface of the solution, and that the part played by the solvent is simply that of a medium in which the solute is suspended, or in which it assumes a state practically equivalent to that of a gas. This conclusion was not received without opposition, especially by the advocates of the so-called hydrate theory, according to which the act of solution involves a more or less intimate or structural union of each molecule of the solute with one or more molecules of water. The trend of opinion at present is toward some form of the hydrate theory, but it does not seem to have been noticed, except by Tammann,[1] that certain properties of solutions are demonstrative against the theory of free solute and inactive solvent, and in favor of the theory that there exists such an interaction between the solute and the solvent that certain properties of the solvent are modified thereby. As the evidence which we have does not go so far as to prove the existence of true hydrates in all solutions, and indeed is rather unfavorable to the hydrate theory, as strictly construed, I prefer to call the theory based upon it the association theory of solutions.

The evidence which proves an efficient interaction between the solute and solvent, and a modification of the properties of the solvent, was discovered by Julius Thomsen.[2] On investigating the heat capacities of many aqueous solutions of electrolytes, Thomsen found that the apparent heat capacity of the solute (that is, the difference between the heat capacity of the solution and that of the

[1] *Zeits. für phys. Chem.*, Vol. 18, p. 625, 1895.

[2] "Thermod. Untersuchungen," Vol. 1; *Wied. Ann.*, 142, p. 337, 1871.

water which enters into it) becomes less as the dilution increases, and in most cases even attains a negative value, so that the heat capacity of a dilute solution is less than that of the water which enters into it. It is manifestly inadmissible to ascribe a negative heat capacity to the solute or to any part of it. It is further impossible to account for the diminished heat capacity by ascribing it to a change in the extent of dissociation due to the rise of temperature during the determination of the heat capacity, for this change has been proved to be so small as to be negligible in this connection. We are therefore forced to believe that the solute, or some part of it, interacts with the surrounding water in such a way as to diminish the heat capacity of the water.

Thomsen also found that the apparent volume of the solute (that is, the difference between the volume of the solution and that of the water which enters into it) becomes less as the dilution increases, and in a very few cases even attains a negative value. In these cases the volume of the solution is less than that of the water which enters into it. It is manifestly impossible to ascribe this result to the shrinking of the solute alone, or to an insertion of the dissociated ions in the interstices between the molecules of water. A similar inference follows to that already drawn from the behavior of the heat capacities, that the solute, or some part of it, interacts with the surrounding water in such a way as to diminish the volume of the water.

We are thus naturally led to speculate on the mode of interaction between the solvent and the solute. Tammann assumes that the effect of the solute extends throughout the solution, so as to produce an interior pressure in it, by reason of which the heat capacity of the solution is altered. He undertakes to calculate the amount of the change by the aid of a thermodynamic formula for the specific heat, involving the specific heat of the solvent under a pressure equal to the assumed interior pressure and a correction term containing the temperature coefficients of volume and pressure. Owing possibly to the difficulty of obtaining accurate data for the necessary calculations, the agreement of Tammann's calculated values with those obtained by observation is not good, though the general course of the observations is fairly well represented.

Jones[1] and his fellow workers have been led by their observa-tions of abnormally great freezing point depressions in concen-trated solutions to adopt the view that the solute interacts with the water to form groups of molecules which are so closely bound together that they move as one body in the solution. Jones calls these combinations hydrates. He explains the abnormality of the freezing point depressions by the hypothesis that the molecules of water which combine to form the hydrates are removed from the solvent so that it contains fewer free molecules or becomes more concentrated than would be inferred from the way in which the solution is made up. By following out this hypothesis he reaches the conclusion that the extent of hydration is a function of the con-centration, being generally greater as the concentration increases at least up to a certain limit.

According to our ordinary conception of the range of molecu-lar force, we should not expect such a variable hydration as is assumed by Jones. We should expect, rather, a practically uniform action of the molecules and ions of the solute, forming groups of water molecules which are constantly the same for all concentra-tions; at least for those in which the groups do not frequently inter-penetrate each other.

In constructing the formulas to represent the heat capacity an the volumes of solutions, I have adopted the simple conceptio which has just been stated. I assume that each undissociate molecule of the solute and each ion of the dissociated molecule interacts with the water around it in such a way as to change it heat capacity and its volume; these changes being the same for al concentrations to which the formulas apply. The solution, then, i considered as a mass of free and unaffected water, in which ar suspended groups of water molecules, surrounding the molecule and ions of the solute, and with their properties modified by th action of the solute. It is not necessary to consider these group as stable. Indeed it is almost necessary, if we are to account fo the laws of electrolytic conduction in harmony with this hypothesis to consider them as extremely loose and unstable aggregations

[1] *Zeitschrift für phys. Chem.*, XLVI., p. 244, 1903; XLIX., 385, 1904.

from which water molecules are continually breaking off to be replaced by others, and through which the ions of the solute may move without dragging with them a load of water molecules. Whether the effect of the molecules and ions of the solute is to increase or diminish the heat capacity or the volume of the water in these groups, or to leave these properties unchanged, is to be determined from the values of the constants of the formulas found for each particular solute.

It should be stated that the solutions to which the formulas have been applied are made up by dissolving one gram-molecule of the solute in N gram-molecules of water. The number of undissociated molecules and the number of the dissociated ions are then expressed as fractions. They are obtained for each solution in the usual manner from Kohlrausch's tables of molecular conductivities.

The formula for the heat capacity formed on this hypothesis reduces to the sum of three terms, of which the first represents the heat capacity of the water used in making up the solution, the second is a constant multiplied by the number of undissociated molecules of the solute, the third, a constant multiplied by the number of dissociated molecules of the solute. The two constants represent the heat capacity of the molecules and ions of the solute respectively, together with the changes which they produce in the heat capacity of the groups of water molecules associated with them.

The formula for the volume assumes the same form, and, *mutatis mutandis,* the interpretation of the constants is the same as that which has just been given.

For solutions of non-electrolytes, in which there is no dissociation, the formula reduces in each case to the sum of two terms, one of which represents the heat capacity or the volume of the water used in making up the solution, and the other is a constant which depends upon the particular solute employed.

These formulas are abundantly verified by comparison with the results of observation. With regard to the non-electrolytes it has been shown[1] that the heat capacity of their solutions, in most cases, is the sum of the heat capacity of the water and of a constant characteristic of the solute. This constant in general is not the

[1] Magie, *Phys. Review,* Vols. IX., XIII.

same as the heat capacity of the solid solute. A similar rule has been shown to hold for the volumes of aqueous solutions of cane sugar by Wade and by Wànklyn, and examples of its applicability to solutions of other non-electrolytes can be obtained by simple calculations from the data given in the tables of specific gravities. The few cases in which this rule does not hold good, notably those of aqueous solutions of the alcohols, may fairly be considered as exceptions which perhaps cannot now be explained, but which we may expect to explain in harmony with our main hypothesis.

With regard to the electrolytes, the observations of Thomsen and other observations made in the physical laboratory at Princeton by Mr. R. E. Trone, can be represented by the formulas with great accuracy and completeness. As I expect soon to publish (in the *Physical Review*) an extended comparison of the data of observation with the numbers calculated from the assumed formulas, I shall content myself here with giving a few typical examples.

The formulas to be illustrated are:

For the heat capacity $H = W + A(1 - p) + Cp$,
For the volume $V = U + D(1 - p) + Fp$,

in which W and U are respectively the heat capacity and the volume of the water used in making up the solution, and p is the dissociation factor, or the number of dissociated molecules of the solute, expressed as a fraction. In the tables N represents the number of gram-molecules of water in which one gram-molecule of solute is dissolved.

The constants C and F express, for the heat capacity and the volume respectively, the effect of both ions of the dissociated molecule. Either one of them may be considered as the sum of two similar constants, each expressing the effect of one of the two ions. If, therefore, we consider solutions of two binary electrolytes, each containing a common ion, the difference between their values of C or of F should be independent of the effect of the common ion, and so should be the same for the same pair of other ions, whatever may be the common ion with which they are connected. This conclusion from the hypothesis is illustrated by the sodium and

potassium chlorides, hydrates and nitrates, for which the differences of the values of *C* are 22, 17, 22, and of *F* are 8, 9, 11.5. It is not found to hold generally true when the barium and strontium chlorides and nitrates are compared with sodium chloride and nitrate. In these cases, I am informed by Professor Hulett, there are reasons to believe that there is a double dissociation of the barium and strontium salts; in which case an agreement could not be expected.

KCl, $A = 96$, $C = -53$; $D = 47$, $F = 22$.

N	*p*	*H* M.	*H* Calc.	*V* Th.	*V* Calc.
15	0.672			300.4	300.2
30	.728			569.0	568.8
50	.753	880.7	882.0	928.2	928.2
150	.787	1777.6	1777.2	1827.3	1827.3
200	.818	3571.8	3572.2	3625.0	3626.0
300	.835	5370.2	5370.2		
400	.848	7167.1	7168.1		

$NaNO_3$, $A = 55$, $C = -20$; $D = 37.5$, $F = 24$.

N	*p*	*H* Tr.	*H* Calc.	*V* Th.	*V* Calc.
10	0.34			212.5	213
25	.514			480.4	480.7
50	.618	908.2	908.6	929.2	929.2
100	.698	1802.7	1802.7	1828.2	1828.2
200	.757	3598	3598.2	3627.0	3627.5
300	.785	5396	5396.1		

NH_4Cl, $A = 39$, $C = -23.1$; $D = 43.5$, $F = 36$.

N	*p*	*H* Th.	*H* Calc.	*V* Th.	*V* Calc.
10	0.593	181.6	182	219.0	219.1
25	.703	443.6	445	488.2	488.2
50	.742	893	893	937.8	937.9
100	.777	1791	1791	1837.7	1837.7
200	.806	3588	3589	3637.6	3637.5

The constant *C* expresses the heat capacity of the ions added to the loss of heat capacity (considered therefore as a negative quantity) of the water associated with them. The negative number obtained by adding *C*, which is always negative, to the negative value of the heat capacity of the ions should express the loss of heat capacity of the water associated with the ions. If we use for the heat capacity of the ions the heat capacity of the molecule com-

posed of them in the solid state, or, if this is not known, make up a heat capacity for them by adding their atomic heats, as determined by Kopp, we find that the numbers obtained, with two exceptions, fall into two groups. For one of these groups, derived from the constants for sodium chloride, hydrate, and nitrate, ammonium chloride, and hydrochloric acid, the mean number obtained is —44.8, with a maximum deviation of less than five per cent. For the other group, derived from the constants for potassium chloride, hydrate, and nitrate, barium and strontium chloride, and barium nitrate, the mean number obtained is —65.7, with a maximum deviation of less than five per cent. We may conclude from these results that the effect of ions of different sorts in diminishing the heat capacity of the water associated with them is in many cases practically the same, but that other ions may exert on the water a very different effect. The presence in one group of all the sodium salts and in the other of all the potassium salts is especially significant of this last conclusion. The differences between the effects of the ions may be represented by supposing that the action of one sort extends only so far as to affect the water molecules immediately contiguous to them, while that of the other sort extends further into the water.

It is unfortunately impossible to test the formula for heat capacity in the region of extreme dilution, but the formula for the volume has been applied to Kohlrausch and Hallwach's determinations of the specific gravity of very dilute solutions in some cases and found to hold with the constants determined from Thomsen's observations at higher concentrations. In the region of high concentration the formulas sometimes fail to reproduce the observations. This can be ascribed, I believe, to the frequent interpenetration of the groups of water molecules which are associated with each molecule or ion of the solute; or, what amounts to the same thing, to the frequent action of two or more molecules or ions of solute on the same set of water molecules.

I would explain in the same way the apparent change in the extent of hydration calculated by Jones and others from the abnormal depression of the freezing points of concentrated solutions.

The hypothesis developed in this paper does not preclude a kinetic explanation of osmotic pressure. This has been shown recently by Lowry[1] and the argument does not need to be repeated here.

The representation of the molecular conductivity as a sum of two ionic velocities, according to the theory of Kohlrausch, seems to be inconsistent with the assumption of any such action between the ions and the water as will form stable hydrates, at least if the only free electric charges present in the groups constituting the hydrates are those belonging to the ions of the solute. If, however, we assume, as has been done in this paper, that the action of the ions does not form stable groups of water molecules, but only such associations of them that the ion can pass through the water without dragging a group of water molecules with it, we can then use this hypothesis without modifying the commonly accepted explanation of electrolytic conduction.

PRINCETON, N. J., April 19, 1907.

[1] *Phil. Mag.*, April, 1907.

THE GROUPS WHICH ARE GENERATED BY TWO OPERATORS OF ORDERS TWO AND FOUR RESPECTIVELY WHOSE COMMUTATOR IS OF ORDER TWO.

By G. A. MILLER.

(*Read April 19, 1907.*)

We shall first give two general theorems relating to commutators[1] which will be used in what follows.

Theorem I. If a commutator is commutative with one of its elements the order of the commutator divides the order of this element.

Theorem II. The smallest invariant subgroup which contains the commutator of two operators includes the commutator subgroup of the group generated by these operators.

To prove the former of these two theorems, it is only necessary to observe that if $c = s_1^{-1}s_2^{-1}s_1s_2$ is commutative with s_1 or s_2 it is also commutative with $s_2^{-1}s_1s_2$ or $s_1^{-1}s_2s_1$, respectively. Hence s_1 or s_2 would be commutative with $s_2^{-1}s_1s_2$ or $s_1^{-1}s_2s_1$, respectively. The proof of the theorem follows now from the facts that the order of the product of two commutative operators divides the least common multiple of their orders, and that the orders of the two factors in the present case are the same. The proof of the second theorem follows from the fact that the two operators in question would correspond to commutative operators in the quotient group with respect to the given invariant subgroup. In particular we have the corollary, *If two operators generate a group the conjugates of their commutator generate the commutator subgroup.*

Let s_1, s_2 be any two operators of orders 2 and 4, respectively, which satisfy the conditions

$$s_1^2 = 1, \quad s_2^4 = 1, \quad s_1s_2^2s_1s_2 = s_2^3s_1s_2s_1,$$

[1] The principal known theorems relating to commutators are found in two articles published in the *Bulletin of the American Mathematical Society*, vol. 4, p. 135 and vol. 6, p. 105.

and consider the four operators

$$s_1s_2^3s_1s_2,\quad s_1s_2s_1s_2^3,\quad s_2^3s_1s_2^3s_1s_2^2,\quad s_2^2s_1s_2^3s_1s_2^3.$$

The common product of the two commutators and of the other two factors is $s_2^3s_1s_2^2s_1s_2^3$. Hence each of these four factors transforms this common product into its inverse. Moreover, the common product of the first and third and of the second and fourth of the four given operators is $s_1s_2^2s_1s_2^2$, and each of these operators transforms this common product into its inverse. From this it follows that the two operators

$$s_2^3s_1s_2^2s_1s_2^3 \text{ and } s_1s_2^2s_1s_2^2$$

are commutative and that the group generated by them is either cycle or the direct product of two cyclic groups. This abelian group, together with $s_1s_2^3s_1s_2$, generates a group (H), which involves $s_1s_2s_1s_2^3$, $s_2^3s_1s_2^3s_1s_2^2$, $s_2^2s_1s_2^3s_1s_2^3$. The order of H cannot be more than twice that of the given abelian subgroup, and H is invariant under the group (G) generated by s_1 and s_2, since s_2 transforms the four generators of H among themselves and s_1 transforms the first two of them into themselves, while

$$s_1s_2^3s_1s_2^3s_1s_2^2s_1 = s_1s_2^3s_1s_2 \cdot s_2^2s_1s_2^3s_1s_2^3 \cdot s_2s_1s_2^3s_1.$$

From theorem II we conclude that H is the commutator subgroup of G and we have the preliminary theorem: If a group is generated by two operators of orders 2 and 4, respectively, whose commutator is of order 2, the commutator subgroup must be of one of the following two types: the cyclic group of order 2, the group obtained by extending a cyclic group or the direct product of two cyclic groups by means of an operator of order 2 which transforms each operator of this direct product into its inverse.

The group generated by H and s_1 is invariant under s_2, since it contains $s_2^3s_1s_2$. Hence the order of G cannot exceed eight times that of H. As the operators of odd order in G (if such operators occur) generate a characteristic subgroup of its commutator subgroup the order of the commutator quotient group is either 4 or 8; that is, the order of G is either four or eight times that of H.

The octic group is clearly the group of smallest order w contains two operators of orders 2 and 4, respectively, whose mutator is of order 2. In this case the commutator subgrou cyclic and the commutator quotient group is the four-group. T is one group of order 16 which is generated by two operator orders 2 and 4, respectively, whose commutator is of order 2. may be defined as the group of order 16 which involves the ab subgroup of type (1, 1, 1) and 4 cyclic non-invariant subgrou order 4. In this case the commutator subgroup is again cyclic the commutator quotient group is of type (2, 1). Since this g of order 16 has a (2, 1) isomorphism with the octic group, since the operators of odd order in G generate a characteristic group, it follows that *every group which is generated by two o tors of orders 2 and 4, respectively, whose commutator is of ord has the octic group for a quotient group, and its commutator tient group is either of type* (1, 1) *or of type* (2, 1).

Suppose that the commutator quotient group of G is of ord If the order of G were divisible by 16 it would have the grou order 16 considered in the preceding paragraph as a quotient gr This is impossible since the commutator quotient group of the l is of type (2, 1). That is, *if the commutator quotient group is of order 4 the order of G is $8m$, m being an odd number.*

If H contains an invariant cyclic subgroup whose order exc 2, the operators of H, which are commutative with a generat this subgroup, constitute an invariant subgroup of G. This in iant subgroup does not include $s_1s_2^3s_1s_2$, and hence it does no H. Since the group of isomorphisms of a cyclic grou and every invariant subgroup which gives rise to an ab oup includes H, the assumption that H contains an in subgroup whose order exceeds 2 has led to a contra n this it follows that the groups generated by $s_2^3s_1s_2^2$ s_2^2, respectively, have at most 2 common operators cyclic groups are either of the same order or the o twice that of the other. In particular, if the order o le by an odd prime number p, the highest power o vides this order has an even index. The main res

which have been obtained may be expressed as follows: *If a group is generated by two operators of orders 2 and 4, respectively, whose commutator is of order 2, the commutator subgroup is either the cyclic group of order 2, or it may be constructed by extending the direct product of two cyclic groups, involving the same odd factors, by means of an operator of order 2, which transforms each operator of this direct product into its inverse.*

It should be observed that the Sylow subgroups whose orders are powers of 2 in the factors of the direct product of the preceding theorem are either of the same order or one of these orders is twice that of the other. In particular, this direct product may be of order 2. In this case H is the four-group. When H is abelian its order can clearly not exceed 8, and when it involves operators of odd order its order cannot be less than 18. The octic group and the given group of order 16 are evidently the only possible groups when H is cyclic and the substitution group of order 64 and degree 8 which may be generated by $s_1 = ae$, $s_2 = abcd \cdot efgh$ is a group in which G has its largest possible value when H is abelian. As an instance of a G which involves operators of odd order we may mention the transitive group of degree 6 and of order 72. This may be generated by $s_1 = ae$ and $s_2 = abcd \cdot ef$, and is the smallest possible group involving operators of odd order, which may be generated by two operators of orders 2 and 4, respectively, whose commutator is of order 2.

Let s_2 be a substitution of degree $2p$, p being any odd prime number, involving only one transposition. Representing s_2 by $a_1a_2a_3a_4 \cdot b_1b_2b_3b_4 \cdot \ldots . l_1l_2l_3l_4 \cdot mn$ and s_1 by $a_3b_1 \cdot b_3c_1 \cdot \ldots . l_3m$, it is clear that s_1, s_2 generate a transitive group of degree $2p$. As the order of H is divisible by p^2 and as it contains a direct product of two cyclic groups whose orders are divisible by p, this direct product must be of order p^2. The order of H is therefore $2p^2$ and H is obtained by establishing a (p, p) correspondence between two dihedral groups of order $2p$. Since s_2^2 is not commutative with any substitution in the direct product of order p^2 contained in H besides the identity, it has p^2 conjugates under this direct product and hence transforms each one of its substitutions into its inverse. From this it

follows that s_2^2 and this direct product generate H, and hence the order of G is $8p^2$. We have thus arrived at an interesting infinite system of transitive groups of degree $2p$ and of order $8p^2$, such that each group is generated by two substitutions of orders 4 and 2, respectively, whose commutator is of order 2.

As an indirect result of the preceding paragraph we have that the group of isomorphisms of the abelian group of order p^2 and type (1, 1) must always include the octic group. As the abelian group of order p^m, $m > 2$, and of type (1, 1, 1, ...) can be made simply isomorphic with itself after any correspondence has been established between two of its subgroups, it follows from the above that *the octic group is a subgroup of the group of isomorphisms of the abelian group of order p^m, $m > 1$*, and of type (1, 1, 1,...), *p being any odd prime number.* In particular, this group of isomorphisms contains two operators of orders 2 and 4, respectively, whose commutator is of order 2.

The main results of the preceding paragraphs may be stated as follows: If G is generated by two operators of orders 2 and 4, respectively, whose commutator is of order 2, then G is solvable and has an $(a, 1)$ isomorphism with the octic group. The commutator quotient group of G is of order 4 or 8. When this order is 4 the order of G is $8m$, m being an odd number, and vice versa. The highest power of an odd prime factor of the order of G has an even index and the Sylow subgroup of this order is the direct product of two cyclic subgroups of the same order. When the commutator subgroup of G is cyclic G is either of order 8 or of order 16 and vice versa. The only other abelian commutator subgroups which may occur in G are the four-group and the abelian group of order 8 and of type (1, 1, 1). The other possible commutator subgroups of G may be obtained by extending the direct product of two cyclic groups by means of an operator of order 2 which transforms each operator of this direct product into its inverse. A cyclic subgroup whose order exceeds 2 which is contained in this direct product is not invariant under G.

UNIVERSITY OF ILLINOIS,
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JONAH'S WHALE.

By PAUL HAUPT.

(Read April 20, 1907.)

In my paper on "Archæology and Mineralogy," which I read at the general meeting four years ago,[1] I remarked that a competent archæologist must have more than a bowing acquaintance with all branches of science. His philological equipment enables him merely to read the records of the past; but even the translation of an ordinary historical text presupposes a large amount of knowledge, not only of philology, history, chronology, geography, ethnology, but also zoology, botany, mineralogy, &c. I pointed out some conclusions which I had reached, on the basis of mineralogical considerations, with regard to two importantant problems in archæology, *viz.* King Solomon's Mines and Alexander the Great's Expedition to the East. I showed that the *lilies* of the Bible were dark purple sword-lilies (*Gladioli atroviolacei,* Boiss.)[2] which the ancients called *hyacinths,* a name which they used also for the purple variety of quartz, which we term *amethyst,* while the *amethyst* of the ancients denoted the rare purple variety of corundum, known as *purple ruby* or *amethystine sapphire.* I also showed that the *stones of Tarshish,* mentioned in the Bible, were ruby-like crystals of cinnabar from the quicksilver mines of Almaden in southern Spain, and that *Tarshish* was a Phœnician word meaning *dressing of ores,* especially *spalling.*[3] Tarshish was the mining region in southern Spain, and the *ships of Tarshish* went to Spain,

[1] See the abstract in the *Johns Hopkins University Circulars,* No. 163, p. 51.

[2] See *Haupt, Biblische Liebeslieder* (Leipzig, 1907) p. 34, n. 20; *cf.* n. 34 to my paper *Difficult Passages in the Song of Songs* in the *Journal of Biblical Literature,* Vol. XXI., p. 68, and my notes on the Book of Canticles in *The American Journal of Semitic Languages,* Vol. XVIII., p. 241.

[3] See Haupt, *Bibl. Liebeslieder,* p. 59, n. 37; *cf.* the *American Journal of Semitic Languages,* Vol. XVIII., p. 230, and the *Verhandlungen des xiii. Orientalisten-Kongresses* (Leyden, 1904) p. 232.

and not to India.[1] The prophet Jonah was commanded to go to the East, to preach repentance in Nineveh; but he boarded a vessel at Joppah, and tried to go West, to Tarshish, *i. e.*, southern Spain.

In the present paper I shall discuss a zoological problem, *viz.* Jonah's whale. Geo. A. Smith has prefixed to his remarks on the Book of Jonah the quotation:[2] ***And this is the tragedy of the Book of Jonah, that a Book which is made the means of one of the most sublime revelations of truth in the Old Testament should be known to most only for its connection with a whale.*** Jonah's whale is the sea-monster which ***swallowed up*** the disobedient prophet and ***vomited him out*** again ***upon the dry land,*** after Jonah had been in the bowels of the monster three days and three nights. The original text speaks only of ***a great fish,***[3] just as the legend of the Fall of Man speaks only of the ***fruit*** of the ***tree of the knowledge of good and evil,*** not of an ***apple***.[4] Not to know good and evil (*i. e.*, what is wholesome and injurious) means in Hebrew to be like a child. He who eats of the forbidden fruit loses his childlike innocence. The Fall of Man is the first coitus—an explanation which was given by the great English philosopher Thomas Hobbes in his ***Leviathan*** (London, 1651).[5]

The popular conception that Jonah was swallowed by a whale is based on the passage Matt. xii, 39–41, where Jesus says: *An evil and adulterous*[6] *generation seeketh after a sign; and there shall no sign be given to it, but the sign of the prophet Jonas.*[7] For as Jonas was three days and three nights in the whale's belly; so shall

[1] See p. 119 of the Critical Notes on the Hebrew text of the Book of Kings in the Polychrome Bible.

[2] In Vol. II. of *The Book of The Twelve Prophets* (London, 1898) p. 492 (*The Expositor's Bible*).

[3] The preceding verb does not mean *prepared* but *detailed, appointed*, *cf.* Haupt, *Purim* (Leipzig, 1906) p. 17, l. 37.

[4] The Hebrew word for *apple* seems to denote the large yellow berries of the mandrake; see Haupt, *Bibl. Liebeslieder*, p. 64; *cf.* the *American Journal of Semitic Languages*, Vol. XVIII., p. 232, n. 5.

[5] See my remarks in the *Journal of Biblical Literature*, Vol. XXI., p. 66.

[6] That is, *idolatrous*.

[7] The wonderful message of God transmitted by Jonah and Jesus is sufficient; *cf.* Luke xi, 30; xvi, 31; also Mark, viii, 12.

the Son of Man[1] be three days and three nights in the heart of the earth. *The men of Nineveh shall rise*[2] *in judgment with this generation, and shall condemn it*,[3] *because they repented at the preaching of Jonas; and behold a greater than Jonas is here.* That is, the Ninevites had more faith than the present generation: when a prophet of Israel preached in a foreign land to the heathen inhabitants of Nineveh, they believed him and turned to God; Jesus, a greater prophet than Jonah, *came unto His own* home, *and His own* people *received Him not* (John i, 11).[4] Matt. xii, 41 is the immediate sequel of v. 39; the intervening verse is a later insertion.[5] Even if these words were authentic, they would not prove that Jesus regarded the history of Jonah as actual history. We may illustrate a point by referring to King Lear without committing ourselves as to the historical accuracy of Shakespeare's tragedy. An astronomer who speaks of a beautiful sunset does not contest the Copernican system.

The Greek text has in Matt. xii, 40 κῆτος (Lat. *cetus*, which means *sea-monster*,[6] but not necessarily *whale*). Any huge marine animal might be called *cetus*, not only a cetacean, but also a large cuttle-fish, or a huge shark, or the enormous sea-serpent, which is said to have been repeatedly seen at sea.[7]

[1] *Son of Man* means simply *man* in Aramaic; see the translation of *Ezekiel*, in the Polychrome Bible, p. 96, l. 51; *cf.* Wellhausen, *Israelitische und jüdische Geschichte* (Berlin, 1904) p. 387, below.

[2] In the Revised Version: *stand up*. For the phrase *to stand in the judgment* see Psalm i and my explanation in *The American Journal of Semitic Languages*, Vol. XIX., p. 132.

[3] That is, if the Ninevites were tried together with this generation for disbelief in revealed religion, they would be acquitted, and you would be found guilty: they would *stand* the test, and you would be found wanting.

[4] *Cf.* Gustav Frenssen's *Hilligenlei*, chapter XXVI., p. 523.

[5] In Luke xi, 29–32, there is no reference to Jonah in the belly of the whale; *cf.* Wellhausen, *Das Evangelium Matthæi* (Berlin, 1904) p. 64.

[6] The Revised Version gives *sea-monster* in the margin. In Gen. i, 21; Job vii, 12, on the other hand, the R. V. substitutes *sea-monster* for the rendering *whale* in the Authorized Version.

[7] The accounts given of the appearance of the so-called *sea-serpent* cannot all be based on inaccurate observations, though it is not certain that this unknown sea-monster is an animal of serpentine form. The President of the *Deutsche Orient-Gesellschaft*, Admiral Hollmann saw a large *sea-serpent* on July 26, 1883; *cf.* A. C. Oudemans, *The great sea-serpent* (London, 1892) and the article, *Das Problem der grossen Seeschlange* by Dr. R. Henning in the Berlin weekly *Daheim* (1906) No. 49.

Some scholars imagined that Jonah merely dreamed that he had been swallowed by a great fish. Others fancied that the prophet was not swallowed, but clung to the belly of the fish.[1] Certain expositors suppose that The Whale was the name of a ship which picked up Jonah, or the name of an inn on the seashore.[2] The famous German student's song (by Scheffel) begins: *Im schwarzen Walfisch zu Askalon da trank ein Mann drei Tag,* and the last stanza is: *Im schwarzen Walfisch zu Askalon wird kein Prophet geehrt, und wer vergnügt dort leben will, zahlt bar was er verzehrt.*

Orthodox theologians who defend the historical character of the Book of Jonah generally presume that the great fish which swallowed Jonah was a shark.[3] Professor Geo. E. Post, of the American College, Beyrout, Syria, saw a shark at Beyrout 20 feet long, and they sometimes attain a length of 30 feet.[4] Sharks may swallow men, and even horses and other large animals whole. In certain theological commentaries[5] we find the remarkable statement that, in 1758, a sailor fell overboard in the Mediterranean and was swallowed by a shark (*carcharias*). The captain commanded to train a gun upon the man-eater, and the monster was hit by a cannon ball. The shark vomited out the sailor who was picked up by a boat; he had hardly suffered any injury. This is reported to have happened in 1758; I did not see it.

Against the traditional rendering *whale* the objection is often raised that there are no whales in the Mediterranean,[6] and that the

[1] See Hastings' *Dictionary of the Bible*, Vol. II. (New York, 1899) p. 749^{b}, below.

[2] See J. D. Michaelis' translation of the Old Testament, Part XI (Göttingen, 1782) p. 100.

[3] *Cf.* C. F. Keil's Biblical commentary on the Minor Prophets (Leipzig 1873) p. 285.

[4] See Hastings' *Dictionary of the Bible*, Vol. IV. (New York, 1902) p. 914^{b}.

[5] See Paul Kleinert in J. P. Lange's *Bibelwerk*, part XIX (Bielefeld, 1868) p. 30^{a}; Keil's commentary, p. 285, below.

[6] The daily papers stated on March 24, 1907, that the Rev. A. C. Dixon of Chicago (who caused comment by his declaration that the Biblical story of Jonah and the whale was perfectly true, and that the Deity could have constructed the whale along the lines of a modern submarine vessel with electric lights and a cabin), when told that whales were never seen in the Mediterranean, replied: There was one there in the early days.

gullet of the whale is not large enough to admit a man. Now there can be no doubt of the existence of whales in the Mediterranean, although the Swedish naturalist and traveler Fredrik Hasselquist states in his *Voyages and Travels*, published in 1766,[1] with reference to Job xli, 1, where the Authorized Version has *whale* in the margin for *leviathan*:[2]—*How could he speak of an animal which never was seen in the place where he wrote, and at a time when he could have no history of Greenland and Spitzbergen.* Dr. Post states that large parts of the skeletons of two specimens of the right whale are preserved in the museum of the Syrian Protestant College at Beyrout. One of these animals was cast up on the shore near Tyre, not far from the traditional site of the ejection of Jonah, which is at *Nabî Yûnus* (Arab. *Khân an-Nabî Yûnus*)[3] near Zidon. The other was drifted ashore at Beyrout itself. The gullet of the *right whale* would not admit a man; but the *sperm-whale*[4] or *cachalot*[5] has a gullet quite large enough to enable him to swallow a man. Sperm-whales are found in the Mediterranean, although they are not frequent.

[1] Hasselquist's *Iter Palæstinum, eller Resa till Heliga Landet* was edited by Linné (Stockholm, 1757). Hasselquist died at Byn Bagda near Smyrna in 1752.

[2] Leviathan = crocodile, behemoth = hippopotamus.

[3] The tomb of the prophet Jonah is shown at *Al-Máshhad* (i. e., *Tomb of a Saint*) representing the Biblical *Gath-hepher* (2 Kings xiv, 25) north of Nazareth; also in the south near the ancient fortress of *Bethsura* (north of Hebron) whose unsuccessful siege (163 B. C.) is alluded to in Eccl. iv, 14; see Haupt, *Ecclesiastes* (Baltimore, 1905) p. 42, n. 6. *Nabî Yûnus* is also the name of the smaller mound southeast of the Acropolis of Nineveh; see my address on the Book of Nahum in Vol. XXVI of the *Journal of Biblical Literature* (p. 2) and *cf.* Bædeker's *Palästina und Syrien* (Leipzig, 1904) pp. 102, 216, 241, 361.

[4] The name *sperm-whale* or *spermaceti whale* is derived from the *sperm-oil* or *spermaceti* found in the cavity of the head of the cachalot. This oily white liquid, which solidifies on cooling, was called *sperma ceti*, because it was regarded as the male spawn (or *milt*) of the animal. Dutch and English whalers formerly called spermaceti *whale-shot*. It is also known as *white amber*; see below.

[5] *Cachalot* is a French loanword. In the new Oxford dictionary *cachalot* is derived from a Romanic word for *tooth*, Gascon *cachau*, Carcassonne *caichal*. The *cachalot* is not a *mysticete*, *i. e.*, a *baleen* or *whalebone whale*, commonly known as *right whale*, but an *odonticete* or *denticete*, *i. e.*, a toothed cetacean.

[6] See Hasting's *Dictionary of the Bible*, Vol. IV., p. 914[b].

In a cuneiform inscription of the Assyrian king Assur-nâçir-pal (885–860 B. C.) we find the statement that his predecessor Tiglath-pileser I (about 1100 B. C.) boarded Phœnician ships at Arvad (near the N. E. end of the Mediterranean) and slew a *blower,* just as the German Emperor a few years ago, during one of his Norwegian cruises, took part in a whale-hunt. The Greek name of the sperm-whale, *physeter,* means *blower,* i. e., spouting up water.[1] In a paper on the cuneiform name of the cachalot (which I read at the annual meeting of the American Oriental Society held in Philadelphia, April 5, 1907)[2] I showed that the *blower* (Assyr. *nâkhiru*) slain by the ancient Assyrian king in the N. E. part of the Mediterranean must have been a *sperm-whale,*[3] because in a passage of the cuneiform annals of Assur-nâçir-pal we read that this Assyrian king received, as tribute from Tyre, Zidon, Arvad, and other places on the Phœnician coast, ivory *teeth of the blower, the creature of the sea.* This *blower* with ivory teeth cannot have been a *narwhal*[4] or *walrus;*[5] these animals are not found in the Mediterranean. The sperm-whale has, on each side of the lower jaw,[6] from 20 to 25 conical (slightly recurved) teeth which consist of the finest ivory. They are about 5 or 6 in. long, projecting about 2 in. from the gum. The upper jaw, which is very much larger than the lower jaw, is destitute of teeth; at any rate the upper teeth are quite rudimentary and buried in the gum.

[1] The *blowing* or *spouting* of a whale is the act of expiration; the visible stream is chiefly condensed vapor like that of human breath on a cold day.

[2] See the *American Journal of Semitic Languages,* Vol. XIII., p. 253.

[3] The blow-hole of the cachalot is near the edge of the snout.

[4] The so-called *horn* of the *narwhal* (which is sometimes ten feet long and which consists of the hardest ivory) is the left upper incisor of the animal, just as the tusks of elephants are incisors. The horn of the *unicorn* in the British royal coat of arms is the tusk of a narwhal; see my remarks in the translation of the Psalms, in the Polychrome Bible, p. 173.

[5] The enormous teeth which protrude like tusks from the upper jaw of the male walrus are canines, just as the large ivory teeth of the hippopotamus, which sometimes reach a length of two feet or more and weigh upward of six pounds.

[6] The scientific name of the *sperm-whale* is *Physeter* or *Catodon macrocephalus.* *Catodon* means *having under teeth.* *Macrocephalus* points to the enormous size of the square head of the cachalot, which represents one half of the entire bulk of the animal and about one third of the total length.

For several centuries ivory was known as *whale's bone* (not *whalebone!*). Shakespeare says: *To show his teeth as white as whale's bone.*[1] The comparison *as white as whale's bone* is proverbial in the old poets. Also the very hard (*petrosal*) parts of the ear-bones of whales resembles ivory, just as the substance of the ear-stones (*otoliths*) of fishes is called *brain-ivory.*

In the second column of the obelisk recording the slaying of a sperm-whale in the Mediterranean at the hands of Tiglathpileser I (about 1100 B. C.) Assur-naçir-pal (885–860) states that he placed two *blowers* of AD-BAR-stone at the gates of the palaces in the ancient capital of Assyria, *Assur,* now known as *Kileh Shergat*[2] where the Germans have been conducting excavations during the past four years under the auspices of the *Deutsche Orient-Gesellschaft.* According to No. 26 of the *Mitteilungen* of this Society (Berlin, April 1, 1905) p. 56, the ideogram AD-BAR means *basalt,* and on p. 53 of the same number the field-director of the German excavations at Kileh Shergat reports that a great many basalt fragments of sculptures have been found, but the restoration of the figures has not been accomplished. Assyriologists did not know that *nâkhiru,*[3] blower meant *sperm-whale.* It is not impossible that the two basalt cachalots of Kileh Shergat will eventually be recovered. The general color of a sperm-whale is a very dark

[1] *Cf.* H. H. Furness' *Variorum Shakespeare,* Vol. XIV.: *Love's Labour's Lost* (Philadelphia, 1904) p. 262.

[2] Arab. *Kal'at Shergât;* see Bædeker's *Syrien and Palästina* (1904) p. 362, l. 5.

[3] Hommel, in his *Geschichte Babyloniens und Assyriens* (Berlin, 1889) p. 532, deemed it possible that the *blower* which Tiglathpileser I slew in the northeastern part of the Mediterranean was a hippopotamus! English Assyriologists explained *nâkhiru* to mean *dolphin.* But the *blower* must have been an exceptionally large and dangerous animal, and comparatively rare in the Mediterranean; otherwise the slaying of this one animal would not have been especially recorded. It seems to have been regarded as the greatest achievement in Tiglathpileser's venatic record, for this feat is mentioned first, before the account of Tiglathpileser's hunting of wild oxen, elephants, lions, &c. The hunting of a cachalot is a much more hazardous undertaking than ordinary whaling. When aroused, the sperm-whales are formidable adversaries. They can completely destroy a whaleboat by crunching it with the teeth or striking with the tail, and by using the enormous head as a ram they can sink small vessels like the ships of Arvad on which Tiglathpileser I embarked.

grey, nearly black on the upper parts, and lighter beneath. The ancient Assyrian sculptors might have imitated this by the use of dark grey and light grey dolerites, or light dolerite and dark anamesite. In the reports of the *Deutsche Orient-Gesellschaft* the stone is called *Basalt lava.* This is very indefinite: any kind of basalt might be called *basalt lava;* all the rocks of the basalt family are of eruptive origin.

The basalt cachalots of Kileh Shergat are probably very large. The giant sperm-whale attains a length of about 100 feet, with a girth of 40 feet. The Arabic name of the sperm-whale[1] is *'ambar* (for *'anbar, 'abbar*) which means *passing through the water;* Heb. *'ovér yam* (Is. xxiii, 2) means *seafaring, passing over the sea. 'Anbar* is also the name of the fragrant substance which we call *ambergris,* i. e., *grey amber,* in distinction from yellow amber (French *ambre jaune,* German *Berustein,* i. e., *lapis ardens*)[2] and *white amber,* i. e., *spermaceti.* While a pound of (purified) spermaceti is worth about 30 cents, grey ambergris is worth about $35.00 per oz. at present;[3] this (wholesale) price is subject to considerable variation. The use of ambergris in perfumery is decreasing. Ambergris is a morbid concretion from the alimentary tract of the sperm-whale, like the *bezoar*[4] found in the stomach and intestines of certain animals, especially the wild goat, *Capra Ægagrus,* known as the *bezoar goat,* which is found chiefly in the mountains of the Caucasus and Persia. The fragrance of ambergris is said to be due to a bacterium, the *spirillum recti physeteris.* Ambergris is usually found floating on the surface of the ocean or cast upon the shore in regions frequented by sperm-whales, sometimes in masses from 60 to 215 pounds in weight. The sperm-whale is most abundant off New Zealand, in the Sulu Sea, about the Cape Verde Islands, and in the Indian Ocean. Roughly speaking we may say that the cachalot is found chiefly betweet lat. 40° N. and 60° S. The

[1] See Hommel, *Die Namen der Säugethiere bei den südsemitischen Völkern* (Leipzig, 1879) pp. 393 and 447.

[2] See my remarks in the *American Journal of Semitic Languages,* Vol. XXIII., p. 242, l. 5.

[3] Black ambergris is cheaper: the wholesale price is $20.00 per oz. at present.

[4] Bezoar is a corruption of the Persian *pâdzáhr* (Arab. *bâdizahr*) a compound of *pâd,* expelling, and *zahr,* poison.

region of Arvad where Tiglathpileser I slew a sperm-whale is S. of lat. 35° N.

In the Ethiopic Bible the name *'anbar* is used for the *great fish* which swallowed Jonah. A sperm-whale might have swallowed the disobedient prophet, but it is, of course, impossible that Jonah should have been alive after having been in the belly of the whale for three days and three nights, although it is reported in the *Neue Luther. Kirchenzeitung* 1895, p. 303, that a whaleman, James Bradley was, in Feb. 1891, swallowed by a whale, and on the following day he was taken alive out of its stomach. He lay in a swoon in the belly of the whale. The sailors had much difficulty in restoring him to consciousness. It was not till after three months' nursing that James Bradley recovered his reason.[1]—After all, he seems to have been more fortunate in this respect than some distinguished Biblical scholars.

We need not trouble ourselves about the miraculous preservation of the prophet: the Book of Jonah is not actual history, but an apologue like the story of the good Samaritan in the New Testament (Luke x, 30–37) or the parable of the three rings[2] in Lessing's *Nathan der Weise*. The Book of Jonah (which may have been composed, like *Ecclesiastes*,[3] under the reign of Alexander Jannæus, about 100 B. C.) represents a Sadducean[4] protest against the Pharisaic exclusiveness based on the conviction that Divine Grace was reserved for the Chosen People, not for the Gentiles. The present Book of Jonah seems to have displaced in the Dodecapropheton a prophecy of the ancient prophet Jonah ben-Amittai, of Gath-hepher, who prophesied (about 785 B. C.) at the time of King Jehoahaz of Israel (*cf.* the Deuteronomistic addition in 2 Kings xiii, 4–6) the deliverance of Israel from the oppression of the Syrians, which was accomplished by Jehoahaz's son, Jeroboam II (see 2 Kings xiv, 25).

[1] See Hasting's *Dictionary of the Bible*, Vol. II., p. 750[b].

[2] This was taken from Boccaccio's *Decamerane, Giornata i, Nov. iii: Melchisedech Giudeo.*

[3] See Haupt, *Ecclesiastes* (Baltimore, 1905) p. 1.

[4] *Sadducee*, righteous is a euphemistic term for *unrighteous*, i. e., *Hellenizer, freethinker;* see Haupt, *Ecclesiastes*, p. 35, n. 1, and the paper *The name Istar* in the *Journal of the American Oriental Society*, Vol. XXVIII.

The sea-monster which swallowed Jonah corresponds to the wonderful creatures in the Arabian Nights, which transport men to the remotest regions. We must assume that the whale swallowed Jonah near Joppa and cast him ashore at Alexandretta. It was easier for Jonah to proceed thence to Nineveh, especially if he went down the Tigris, than to return to Jerusalem.[1] A sperm-whale could easily swim from Joppa to Alexandretta in three days and three nights; the distance is only about 300 miles. The cachalot swims, as a rule, at a rate of from 3 to 7 miles an hour, and just under the surface of the water. If a sperm-whale swam seven miles an hour, it might rest more than nine hours a day and still cover the distance from Joppa to Alexandretta in three days and three nights, *i. e.,* 72 hours. If Jonah had traveled overland on horseback, it would have taken more than two weeks. The trip from Joppa to Haifa, which represents but one sixth of the entire distance from Joppa to Alexandretta requires from two to three days. A day's journey on horseback is about 25 to 30 miles. The gait of the horses in Palestine is a brisk walk; they hardly ever trot.

The sea-monster was suggested to the author of the Book of Jonah by the local legends connected with Joppe.[2] According to tradition, Andromeda was chained to the rock on the southern side of the narrow opening in the low ledge of rock forming the harbor of Joppa. Andromeda was there exposed to a sea-monster, but was rescued by Perseus, just as the Trojan princess Hesione was delivered by Hercules from a marine monster. The myth of

[1] The overland journey from Alexandretta to Diârbekr (through Aleppo and Urfa) may be made in about 10 days, and the rafting on the Tigris from Diâbekr to Nineveh requires but four days, when there is plenty of water (*i. e.,* from April to June). Ancient Assyrian rafts, supported by inflated skins, and modern *keleks* on the Tigris are figured on pp. 124 and 125 of the translation of *Ezekiel* in the Polychrome Bible.

[2] Cheyne remarks in his *Encyclopædia Biblica* (col. 2574, below) that the sea seemed more alive near Joppa than elsewhere, and the living powers in certain waters was frequently held to be derived from serpents or dragons. In Babylonian mythology the dragon *Ti'âmat* is the personification of the primeval ocean. The ocean was imagined as a broad circular stream encircling the disk of the earth; see my paper *The Rivers of Paradise* in the *Journal of the American Oriental Society,* Vol. XVI., p. ciii, and my remarks on the Babylonian map of the world in the translation of *Ezekiel* (in the Polychrome Bible) p. 100, l. 35.

Perseus and Andromeda reappears in the legend of the patron saint of England, St. George[1] and the Dragon in connection with the city of Beyrout in northern Syria. The Bay of Beyrout is known as St. George Bay, and the belief in a hugh sea-monster is still rife there. The Chaplain to the Church of Scotland at Beyrout, Geo. M. Mackie, states[2] that when a few years ago a Belgian steamer reaching Beyrout at midnight blew her siren whistles to inform the agents of her arrival, the unprecedentel shriek, which startled the whole town out of sleep, was supposed to be the howling of the marine monster, and next day the chief topic of conversations in the bazaars was the visit of the *beast of the sea* during the previous night.

Josephus[3] and Pliny[4] state that the holes where the staples of Andromeda's chains had been driven into the rock were shown at Joppa, and Pliny relates that the bones of the sea-monster to which Andromeda is said to have been exposed were brought from Joppa to Rome and exhibited with a number of other curiosities under the edileship of Marcus Scaurus (58 B. C.). This skeleton was 40 feet long; the ribs were larger than those of the Indian elephant, and the spinal column was about 1½ feet thick.[5] This is preceded by the statement that a sea-monster is said to have been cast ashore, near Cadiz in Southern Spain, which measured 16 cubits between the ends of the flukes and had 120 teeth from 6 to 9 in. long.[6] Sixteen Roman cubits would be about 23 feet,

[1] St. George is said to have been a tribune (of Cappadocian extraction) in the Roman army at the time of the Diocletian persecution of the Christians, who, about 303 A. D. was put to death in Nicomedia.

[2] See Hastings' Dictionary of the Bible, Vol. II, p. 755[a], n. †.

[3] Bell. Jud. III., 9, 3: ἔνθα τῶν Ἀνδρομέδας δεσμῶν ἔτι δεικνύμενοι τύποι πιστοῦνται τὴν ἀρχαιότητα τοῦ μύθου. *Cf.* Strabo, § 759: ἐνταῦθα δὲ μυθεύουσί τινες τὴν Ἀνδρομέδαν ἐκτεθῆναι τῷ κήτει.

[4] *Nat. Hist.*, v, 69: *Iope Phoenicum, antiquior terrarum inundatione, ut ferunt, insidet collem præjacente saxo in quo vinculorum Andromedæ vestigia ostendunt; colitur illic fabulosa Ceto. Cf.* Ovid, *Metamorph.* iv, 670.

[5] Plin. *Nat. Hist.*, IX., 11: *Beluæ cui dicebatur exposita fuisse Andromeda ossa Romæ apportata ex oppido Judææ Iope ostendit inter reliqua miracula in ædilitate sua M. Scaurus, longitudine pedum XL, altitudine costarum Indicos elephantos excedente, spinæ crassitudine sesquipedali.*

[6] *Turranius prodidit expulsam beluam in Gaditano litore cujus inter duas pennas ultimæ caudæ cubita sedecim fuissent, dentes ejusdem CXX, maximi dodrantium mensura, minimi semipedum.*

and the flukes of a giant sperm-whale may be 23 feet between their extremities, although 12 to 15 feet is a more frequent measurement. The teeth of a sperm-whale are, as a rule, 5 or 6 inches long, not 6–9 inches, and the number 120 appears to be due to a misunderstanding: the original report may have been that this marine monster had 60 teeth on both sides of the lower jaw, which may have been misinterpreted to mean: sixty teeth on each side of the lower jaw. As a rule, a sperm-whale has from 20 to 25 teeth on each side of the lower jaw, according to the age of the animal. Pliny says of the *physeter*, i. e., the *sperm-whale:* it is the largest animal in the Gallic ocean, *i. e.,* the Bay of Biscay. It raises itself like an enormous pillar, towering above the sails of the vessels[1] and spouting a flood of water.[2] Cachalots often raise their enormous square head above the water, and the head of a giant sperm-whale may be more than 30 feet long.

There is no reason for doubting the statement that there were some chains fastened to one of the rocks near the entrance to the port of Joppa; nor is there any reason for discrediting the report that the skeleton of a sea-monster was brought from Joppa to Rome in 58 B. C. A large sperm-whale may have been drifted ashore at Joppa, and the skeleton may have been left there for a long time until it was finally carried to Rome at the time of Cicero. The legend of the maiden exposed to the sea-monster and rescued by a gallant hero is a subsequent embellishment of popular fancy,[3] suggested by the presence of the huge skeleton on the beach, and the author of the Sadducean apologue known as the Book of Jonah

[1] The masts of ancient vessels were not very high. A terra-cotta model of a Phœnician ship is figured in the translation of *Ezekiel* (in the Polychrome Bible) p. 149.

[2] Plin. *Nat. Hist.* IX., 8: *Maximum animal . . . in Gallico oceano physeter ingentis columnæ modo se attollens altiorque navium velis diluviem quandam eructans.*

[3] *Cf.* the legend of King Bodo and Brunhildis in connection with the granite cliff, known as *Rossmannshöhe*, in the Hartz mountains, and the legend of the *pillar of salt* in the story of Lot (Gen. xix, 26; Luke xvii, 32). See the picture of the pillar of salt at Usdum facing p. 308 of Lynch's *Narrative of the U. S. Expedition to the River Jordan and the Dead Sea* (Philadelphia, 1850).

introduced the sea-monster (or giant-sperm-whale) of Joppa in order to transport the disobedient prophet as speedily as possible from Joppa, the sea-port of Jerusalem, to Alexandretta, the terminus of the shortest route from the Mediterrenean to Nineveh.

The grotesque idea that the prophet composed an elaborate poem in the belly of the whale must not be credited to the author of the story. Even Luther said, Jonah hardly felt so well as to sing so fine a song.[2] This psalm is a later insertion, just as the Song of Hannah (in the Books of Samuel)[3] and Moses's Song of Triumph (in the Book of Exodus).[4] The editor who inserted the psalm in the Book of Jonah misunderstood the metaphorical expressions *sea, ocean, surge,* and *billows,* which are used in Hebrew for *distress, disaster,*[5] and which refer here especially to the Syrian persecution at the time of Antiochus Epiphanes (about 168 B. C.).[6] This Maccabean poem, which has no connection whatever with the legend of Jonah, may be translated[7] as follows:[8]

A i 2 When in distress I called,
JHVH responded;
From depths of Sheol I cried;
My voice was heard.

That is, whenever Israel was in distress, JHVH heard their prayers,

[1] The theory that the *great fish* which swallowed Jonah was a *cachalot* was advanced by Quandt, *Jonas der Sohn Amithai* (Berlin, 1866) cited (but rejected) by Paul Kleinert in J. P. Lange's *Bibelwerk,* part XIX. (Bielefeld, 1868) p. 28, below.

[2] *Sowohl ist ihm nicht gewesen, dass er hätte mögen solch ein feines Liedlein singen.*

[3] See my paper *The Prototype of the Magnificat* in the *Journal of the German Oriental Society,* Vol. LVIII (Leipzig, 1904) p. 617.

[4] See my paper in the *American Journal of Semitic Languages,* Vol. XX., p. 15[illegible]

[5] Sha[illegible]re says: *deep-drenched in a sea of care* and *what a tide* [illegible]shing on this woeful land at once!*

[6] [illegible] my translation of the Book of Nahum in Vol. XXVI. of the [illegible]al *Literature* (p. 17).

[7] [illegible] omitted in the present translation represent subsequent [illegible]storation of the original text in the *American Journal of* [illegible] Vol. XXIII., p. 256.

[8] [illegible] my translation has been much improved in a number [illegible]stance of the distinguished coeditor of the Poly-[illegible]ward Furness.

ı Israel seemed to be annihilated for ever at the tir
nezzar.

Thou plungedst me into the sea,
  The ocean engulfs me;
Thine every surge and billow
  Over me they pass.

rs to the Syrian persecution at the time of Anti
·.

i 4 I thought, lo! I am banished
  From thy presence for ay;
How again shall I see
  Thy Holy Temple!

eemed as though the religion of the Jews was to be extermi
ever; even the Temple on Mount Zion was in the hands c
ıen for three years, until it was reconsecrated by Judas
ɔæus in Dec. 165.[1]

iv 6 To the depths of the sea, I descended,
  To perdition[2] for ay;
Tangle enveloped my head,
  Sheol's[3] bolts barred me.

ael was almost submerged and drowned; Hellenic cı
threatened to engulf and bury Judaism for ever.

C v 7 When in me my soul fainted,
  I thought on JHVH;
To Thee my prayer arose,
  To Thy Holy Temple.

When Judaism was *in extremis,* the Maccabees began their war, and their faith was gloriously rewarded by JHVH.

vi 8 Who worships false follies,[4]
  Forsakes his boon;[5]
9 But I with songs of praise
  Sacrifice to Thee.

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[1] See my explanation of Ps. xxiii in the *American Journal of S* *Languages,* Vol. XXI., p. 152.

[2] Lit. *to the earth,* i. e., the *netherworld,* Hades.

[3] Lit. *her* bolts, referring to the netherworld.

[4] That is, the Greek gods.

[5] God's love and grac

COMPARISON OF LATITUDE OBSERVATIONS AT SAYRE OBSERVATORY, SOUTH BETHLEHEM, AND AT FLOWER OBSERVATORY, PHILADELPHIA,

FROM SEPTEMBER 30, 1904, TO SEPTEMBER 3, 1906.

BY JOHN H. OGBURN.

(*Read April 20, 1907.*)

This paper is based on two years work on latitude determination at Bethlehem compared with that obtained during the same period at Flower Observatory, the results of which Professor Doolittle has kindly furnished me in advance of publication.

The Sayre Observatory at South Bethlehem, under Professor Doolittle's direction, was among the first to be devoted to this class of work and the observations, continuing through a period of nearly twenty years, resulted in a series which has been an invaluable aid in the discussions of the laws of the variation of latitude. It was thought that a continuation of the same class of work for some years might be desirable as it would result in a longer series at a given point than could be found elsewhere.

To aid in this project, the late Mr. Robert H. Sayre, one of the trustees of Lehigh University, furnished the means for procuring a modern zenith telescope and a suitable house for it.

The zenith telescope house was erected in the spring of 1904 according to plans which conform to those of the International Latitude Stations and is composed of wood excepting the roof which is of tin. The walls are double, with an air space of one foot between the inside ceiling and the latticed exterior. The inside dimensions are, 10 feet square with walls 7 feet high. The roof is divided in the middle and the two halves move on pinions giving a maximum opening of 6 feet. The object glass of the telescope, when pointing to the zenith, is about 2 inches below the top line of the walls.

The pier is composed of concrete, the top face being 27 inches square, and rises from a foundation of the same material in the form of a cube whose dimensions are 5 feet, placed wholly beneath the surface of the ground.

The zenith telescope is from the work-shop of Warner and Swasey, the optical parts by Brashear. The clear aperture of the object glass is 4½ inches, its focal length 48 inches and is furnished with electric illumination. The base and vertical axis are of massive construction. It maintains its position in adjustment with little variation. A magnifying power of 144 has been employed throughout. No record of errors in azimuth, collimation and level has been kept. The sum of these corrections for any star of the observing list during the period embraced by these observations was always less than one second of time.

The observations were made with a view of determining a value for *the Constant of Aberration* according to the plan suggested by Dr. Küstner of Berlin. This entails the grouping of the greater part of the observations around four periods in the year which include about eight months altogether, but their distribution is such that the results are equally available for investigating the variation of latitude. The method of conducting the observations has been identical with that followed at Flower Observatory. Since the two stations are practically on the same meridian and the declinations of the stars are eliminated, the two series are directly comparable.

At Bethlehem the list of stars comprise 4 groups of 10 pairs each and the usual adjustment of each observed latitude to the mean latitude which would result from the average of the 80 stars declinations have been made. Observations for investigating the effect of temperature on the micrometer value were made by two methods and the final results for the temperature coefficient for the two years are in such close agreement as to inspire some confidence in their trustworthiness. These values for the two years, in units of the sixth decimal place are 146 and 138. The individual determinations are so discordant, however, that I have not considered their introduction into the reductions advisable, since the average correction for the micrometer for any group of stars is less than one

revolution. The probable error of latitude from one pair of stars —the part due to observation alone—for the two years was $\pm 0''.121$ and $\pm 0''.112$ respectively.

The following work is an attempt to find whether the abrupt deviation at irregular intervals of the observed latitude from the mean value by an amount many times its probable error at *Bethlehem* is duplicated in a greater or less degree at *Philadelphia*.

Thus, at Bethlehem the observations gave for the ten pairs

$40^\circ 36' 20'' +$					
May 21, 1906	3″.58	3″.54	3″.56	3″.74	3″.80
On next observing night	3 .88	3 .83	3 .92	3 .74	3 .94
The differences	+0 .30	+.29	+.36	+00	+.14

					Mean
3″.60	3″.78	3″.74	3″.75	3″.74	3″.68
3 .99	3 .84	4 .12	3 .82	4 .10	3 .92
+.39	+.06	+.38	+.07	+.36	+.24

The first values give a latitude agreeing closely with the finally deduced value for that date; therefore the difference, $0''.24$ represents a departure from the mean of 7 times the probable error.

By applying the average difference between the two stations to the latitude at Philadelphia we can construct a diagram which very nearly represents the efforts of two independent observers to follow the motion of the pole at a given meridian. (Page 170.)

The observations at each place for any day on which no corresponding observations at the other place were made have been omitted so that the diagrams represent about half the observations at Philadelphia and two-thirds those at Bethlehem.

The two curves agree pretty closely as to the lengths of the periods and total variation, but the maximum and minimum values at Philadelphia fall about three weeks earlier than the corresponding phases at Bethlehem.

Two methods will be employed in the comparisons.

First Method.

The observations were divided into periods of about forty days each and the means of the latitude for each of these periods found. The simple difference was taken between the latitude for each group

and the mean of the corresponding forty day group in which it is found and the result for each station tabulated side by side.

Omitting all record of groups where the observations were less than 4, there remian for comparison 209 groups which give the following results.

Cases where one or the other residual was zero = 27.
Cases where both residuals were greater than 0''.15 = None.
Cases where both greater than 0''.10 = 10: — 7 "like," 3 "unlike."
Cases where smaller residual was > 0''.05 and < 0''.10 = 62: — 35 "like," 27 "unlike."
Cases where smaller residual was between 0''.00 and 0''.05 = 109: — 54 "like," 55 "unlike."

An actual departure at both places from the mean latitude in the same direction should manifest itself in the majority of cases by an agreement of sing in these residuals. This is actually found in the case of the residuals greater than 0''.10 but the total number of cases is too small to have much weight. Irrespective of the magnitude of the residuals there are 96 "alike" and 85 "unlike." If the two series of observations were entirely independent the theory of probability would require that the number of "like" and "unlike" be 90 each and the difference between this and the actual numbers is so small the inevitable conclusion follows that the two series are practically independent.

Second Method.

Excluding all work in which a determination at either place on any night depends on the observations of less than six pairs there remain 123 common dates which represent 3,410 separate determinations, 1,730 at Philadelphia and 1,680 at Bethlehem. By constructing to a generous scale the diagram just shown on the screen and drawing smooth curves for the two sets of observed latitudes we may consider these curves as the actual values of the latitude during the period represented in this comparison and the differences between the latitudes at each station and the value derived from the curve will give us a set of residuals which should be a measure of the precision of one night's work on the supposition that the variation is represented by long periods.

Let ΣV_1^2 and ΣV_2^2 be the sum of the squares of the residuals at Philadelphia and Bethlehem respectively. Evidence of systematic fluctuations would be shown if $\Sigma V_1^2 + \Sigma V_2^2$ is appreciably greater than ΣV_3^2 where ΣV_3^2 is the sum of the squares of the residuals derived directly from the differences of the observed latitudes.

These last residuals must be derived in a way that will eliminate the systematic divergence resulting from an apparent constant difference in the times of maxima and minima at the two places. This has been effected by considering V_3 as the algebraic difference between V_1 and V_2. Without reproducing the details the following results were found.

$$\Sigma V_1^2 = 0''.5706$$
$$\Sigma V_2^2 = 0\ .6993$$
$$\Sigma V_3^2 = 1\ .2718$$

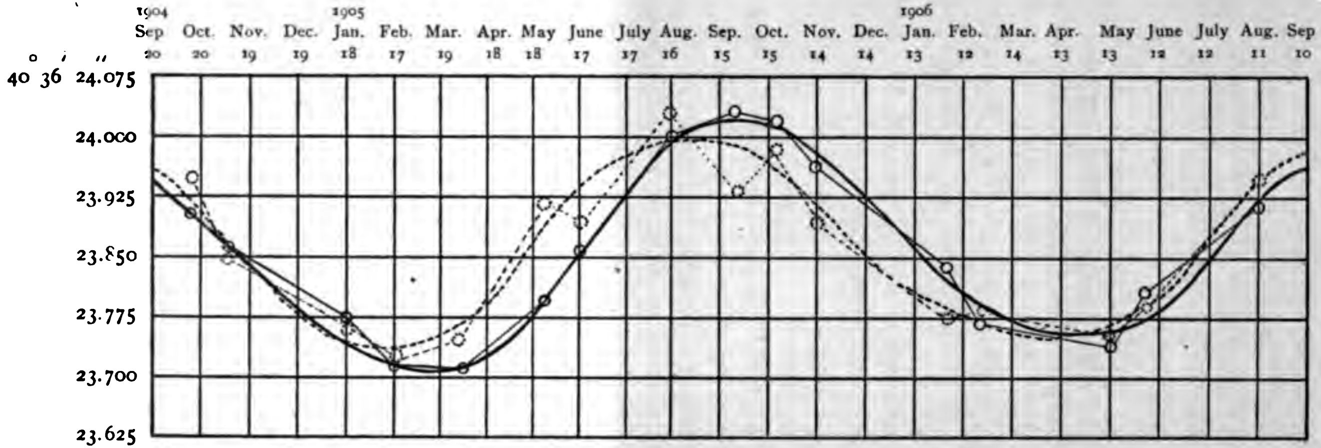
Since $\Sigma V_1^2 + \Sigma V_2^2$ differs from ΣV_3^2 by less than $0''.002$ it is evident that these observations show no relation between abnormal values of observed latitude at the two stations.

If the residuals are reduced to probable error there results:

For one night's determination from 10 pairs—

at Philadelphia $\pm 0''.053$: For one pair $\pm 0''.17$.
at Bethlehem $\pm 0\ .057$: For one pair $\pm 0\ .18$.

The part in this latter due to observation alone was nearly $\pm 0''.12$ leaving $\begin{matrix}\pm 0''.13 \\ \pm 0\ .14\end{matrix}$ at the two places for the probable error of one observation which is apparently beyond the observer's influence.



Graphical representation of the variation of latitude as observed at the Flower Observatory, Philadelphia, and the Sayre Observatory, South Bethlehem.

NOTE.—The latitudes of Flower Observatory have been increased by 38′ 21″.744, the mean difference in latitude between the stations.

Dotted curve.—Philadelphia.

Full curve.—South Bethlehem.

TRANSPORTATION IN THE UNITED STATES.

By LEWIS M. HAUPT.

(*Read April 19, 1907.*)

When, in the early dawn of Friday, October 12, 1492, the natives of the Isla Guanahani, saw three phantom caravels bearing down upon their homes, it is said, they were so amazed that they ran to cover and exclaimed, "*Nous sommes Decouvert.*"

Possession was immediately assumed by Columbus in the name of Spain and the possibility of thus acquiring great wealth and dominion by the right of discovery, stimulated many adventurers to cross the Atlantic, but no permanent settlements were effected until the Spanish established a colony at St. Augustine, Florida, August 28, 1565, and the English at Jamestown, Virginia, under Captain John Smith. in April, 1607.

Then followed several centuries of colonial governments with their incidental contests for trade and territory and confiscation of native right until the conditions became so intolerable as to compel a confederation for mutual defense which finally led to the formation of the republic on the seventeenth day of September, 1787.

Up to this date, the resources of the country being exhausted by war, and the population greatly scattered, little attention could be given to any general plan for the conduct of domestic commerce although a few of the states had made explorations and granted charters for the building of canals and the improvement of rivers.

One of the earliest of these was the project endorsed by the American Philosophical Society, for the creation of a waterway between the lakes and the seaboard, which was surveyed and recommended by Provost Wm. Smith and David Rittenhouse, both of this Society, in 1770, leading to the construction of the Schuylkill and Susquehanna Canal some years after. In 1785 Washington was made President of the Potomac Company to connect the Chesapeake Bay with the Ohio River and on January 5, of the following year, the James River and Kanahwa Canal was incorporated.

The discovery of coal in Pennsylvania in 1792 greatly stimulated the opening of canals in the middle and eastern states under corporate control, and in a few instances the government became interested by subscribing to the stock of the companies, as in the case of the Dismal Swamp, the Chesapeake and Delaware, the Louisville and Portland canals.

Thus fostered and encouraged the mileage of the canals increased rapidly and on safe commercial routes, so that up to the date of the Civil War there were over 5,000 miles in operation estimated to have cost $150,000,000 while in the same time the general government had expended less than $15,000,000 on its waterways.

With the incoming railroad epoch, in 1830, the trend of investments changed and as the roads soon discovered their inability to compete with the cheaper water routes, maintained by the states, and also to pay a tax on their tonnage, a war of extermination was waged and in time these ancient servitors of the public were forced to the wall.

These primitive railways, operated at first by horses and later by small wood-burning engines, followed the canal routes as being those of least resistance and greatest traffic, but carried very little freight, and efforts were made to restrict their business exclusively to passengers, but it was not successful.

Thus along the line of the Erie Canal there were nine independent railroads; the first of which extended from Albany to Schenectady, opened in September, 1831, or six years after the canal. These links were subsequently united and in 1851 the Hudson River road was completed and an all rail connection made over this route with the lakes.

Similarly the Pennsylvania Railroad was built from Columbia up the Susquehanna and Juniata to Hollidaysburg, thence crossing the mountain on the old Portage Railroad to the Conemaugh at Johnstown and thence to Pittsburg via. the Kiskiminitas and Allegheny. The total distance from Philadelphia was about 395 miles by this route. The railroad was opened through to Pittsburg, December 10, 1852, and soon after, the improvement of the Ohio was urged by the president of the company as the best method of increasing the traffic of his lines.

The Baltimore and Ohio was also pressed westward along the Potomac, following closely the lines of the Chesapeake and Ohio Canal to Pittsburgh and Wheeling, which latter was completed in 1851 at a cost of $11,071,000. The railroad was opened to Harper's Ferry, 82 miles, in 1834 at a cost of $4,000,000. When extended to Chicago, 795 miles, the capital reached $57,000,000.

The Delaware and Raritan Canal, which was controlled by Commodore Stockton, was so bitterly opposed by John Stevens who was applying for a charter for the Camden and Amboy Railroad that it was found only possible to secure either by a consolidation of the two companies requiring both to be completed and opened at the same time.

From these early beginnings the contest between the two systems for the internal traffic of the country waxed warm and the higher speed and greater latitude of the railroads enabled them to tap the business at its sources and retain it at the expense of the canals. Frequently where this could not be done, the canals were leased for long periods of years and the tonnage diverted even at a heavy charge for the maintenance of the canal. Such leases by common carriers, exercising the rights of eminent domain, should never have been authorized as they are clearly against the public interest and in restraint of trade.

So rapidly has this extermination of the waterways proceeded that in this great commonwealth where there were 1,084.87 miles in operation, in 1872, it was reduced to only 217 miles (as reported by the census of 1889) while the last report of the Secretary of Internal Affairs states: "At the time of the sale of the public works many years ago, it was in the contract of the sale that the canals should be kept open by the purchaser for the convenience of the people in the transportation of their productions."

"The canal of Pennsylvania is a reminiscence. It is not easy to discover the bed of the old canal. The levelling process is rapidly filling up its trenches and the young growth of timber has obscured its location." Then follows the very significant remark that: "The average receipts per ton mile upon all the railroads are very much lower than they were when the canals of Pennsylvania were all in operation," and also the average rates on the New York

Central and Hudson River Railroad which is in competition with the enlarged Erie Canal, are so much higher than those on the Pennsylvania Railroad, that had the latter been able to charge the New York rates on the business of last year, "its increase in freight revenue alone would have been upwards of six and a half million dollars."

From which it is concluded that Pennsylvania does not need canals to secure low rates.

These data point inevitably to the fact that because of her waterway the state of New York is enabled to secure a lower rate on a large part of her crude materials, and supply her mills and factories without requiring the railroads to carry so much of this class, at about cost, to keep the wheels of industry in motion, and that in consequence the railroads have a larger tonnage of higher class freight and are making more money. Under this exhibit would it not be good policy for the railroads of Pennsylvania to expend some six millions annually for a few years to enable them to increase their revenues permanently by not less than that amount? In fact a prominent official stated only last week that what Pennsylvania needed most for transportation was the restoration of her abandoned canals.

There is an inherent difference between the railroad and other systems of transportation which enables its managers to control it absolutely, and although it is supposed to be built by public funds under state and government laws, the public has little or nothing to say as to its policy or control. In fact, its own board is never sure it has the control of its property, if large blocks of its securities are on the market. But the patricular feature to which attention is directed is the impossibility of any one shipping his own goods, in his own vehicle, and at his own convenience as is the case with a waterway, or a road. This feature makes it possible to so control the movements of freight as to have led in the past to many and serious irregularities, discrimination, rebates, special charges for terminal facilities, demurrage, warehousing, failures to supply cars, and many other acts in restraint of trade.

The railroads should be regarded as a public trust and not a device for the acquisition of great wealth for those in control. It

is also unwise to attempt to fix rates by legislation since the physical conditions, traffic and character of business and population are the principal elements in the adjusting of tolls which can best be determined by the integrity of the officers in charge.

In a recent lecture on railroad safety devices, Mr. J. C. Irwin, superintendent of construction of the New York Central Railroad stated that "the tremendous prosperity in this country is certainly the cause of the chief troubles in the operation of our roads at the present time. The traffic has increased so rapidly that the efforts to increase facilities have not been able to keep up with it. The increase in trackage has been almost nothing in comparison to the tremendous increase in freight tonnage. The large expenditures for modern freight yards have often resulted in little more than additional storage room for cars, mainly from lack of sufficient main line trackage or of properly located warehouse facilities. This overwhelming business has also manifested itself in the demoralization of the operating force. The rates of pay have been constantly increased yet the demand for skilled labor makes it almost impossible to get enough good men for the service."

This is not a recent discovery, however, for as long ago as 1892 the president of the Pennsylvania Railroad stated that there was then a larger amount of tonnage tendered to the railways than they were properly able to handle, while at the same time the competition between the transportation lines of the country was more active and the traffic carried at lower rates than at any other period of their history. From these statements it should not be expected that relief will be secured by legislation reducing the maximum tariffs as this would have the double effect of driving some of the smaller lines out of business and also increasing the tonnage on those that remained, resulting in greater delays and risks.

To ascertain just where the weak spot is located an analysis has been prepared of the most important elements of this problem showing the increments of population, tonnage, trackage, equipment and yardage, from which it appears that the railroads are absolutely unable to meet the present demands of traffic, with no possibility of providing for the future excepting by a radical modification of their policy of absorption, by the substitution therefor

of one of segregation and dispersion to the waterways, as soon a they may be put in condition for the traffic which has been diverte for so many years, and for the maintenance of which the Nationa appropriations, although large, have been wholly inadequate an inefficient.

Mr. J. J. Hill has repeatedly shown so forcefully the impossi bility of meeting the demand for the additional trackage that is hardly necessary to reiterate, save for the record. He said "Th traffic of the country is congested beyond imagination. The com merce of the country is paralyzed, and continued, it means slo death." The money required to restore the equilibrium would more than double the whole amount in circulation and the enti capacity of all the rolling mills could not furnish the stock even the men and the money were at hand. This is certainly a criti condition and so he recommends a canal down the Mississippi vall from St. Louis to the gulf, as a measure of relief. Has this gr and experienced railroad president drawn on his imagination? F from it he has pointed out the only possible remedy which t physics of the country affords, namely the subdivision into tru line water routes with short tributary rail deliveries to numero local points of distribution, and the substitution of the vessels much larger capacity for the small car-units which cannot be handl to advantage. The system must also be one which can be operat throughout the entire year and therefore its outlets should be latitudes below the winter frosts, as much as possible.

But to return to the data and their deductions, and for conve ence arranging them in tabular form for the decade 1895–19 there follows:

[illegible] OF THE TRANSPORTATION PROBLEM.

Population.

1895	1905	Increase.	Per Cen
69,500,000	86,100,000	16,600,000	23.5
	Trackage		
177,746	216,973	39,227	22
12,348	19,881	6,533	53
43,181	69,941	26,760	62
233,275	306,796	73,521	31

Tonnage Carried.

Tons.	755,799,883	1,435,321,748	679,521,865	90
Ton-miles, etc.	88,567,770,801	187,375,621,537–	98,807,850,736–	111–
Tons per mile.	4,362	6,681	2,418	57

Rolling Stock.

Locomotives.	36,610	49,616	13,006	35
Freight cars.	1,230,798	1,757,105	526,307	43
Tractive Power.	13,700	28,700	15,000	109

Freight car capacity increased over				120
Tons per capita.	10	15	5	50
Tons-miles capita.	1,160	1,000	840	72

Thus while the mileage has not even kept pace with the increase of population the tonnage has multiplied five fold. This has been met by increasing the number and capacity of the freight cars as well as the weight and tractive power of engines, requiring in many instances large expenditures for betterments in track and equipment.

But still the cars accumulate in yards and sidings and it is found that while the actual average haul of 130 miles can readily be covered in eight hours after the train is made up that the delays in the loading, unloading, assorting and storing of these multitudinous units requires from six to eight days which reduces the actual efficiency down to only about six per cent. To increase the number or capacity of the cars would not relieve the congestion, but as about one half of the tonnage is coal and ore it would be greatly simplified if these products were carried on the restored water channels which they once followed at lesser cost to the consumers.

It is worthy of note that this enormous railroad system for the carriage of interstate commerce, has been developed mainly by the contributions of moneys from public and private investors, amounting to more than sixteen and a quarter billions of dollars, entrusted to corporations, exercising the rights of eminent domain under state and national authority, and it has covered the populous sections of the country with such a ramification of roads as to leave little opportunity for additional, independent lines to be built. In the more sparsely settled west the increase is still progressing with the result of adding more traffic to the already engorged roads as

well as to the length of haul, if the present Atlantic ports are to hold the trade. But the ratio of the growth in the mileage is rapidly decreasing for in the several decades ending with the years, as stated, the percentages of increase in main line mileage was as follows:

1845, 323%; 1855, 295%; 1865, 291%; 1875 111%; 1885, 73%; 1895, 41%; 1905, 21%;

showing that the construction of track is relatively losing very rapidly, as compared with the ratio of growth in population, and especially in tonnage; for within the next generation the population of this country, which is increasing more rapidly than any other civilized nation, will have doubled.

The total tons of freight carried on all lines in 1905 was 1,435,321,748 carried at an average charge of 0.784 cents making the total tax paid for rail transportation per ton for the average distance of 130.4 miles amount to $1,469,518,157. The cost of handling this freight before and after reaching the railroads is no doubt as much more, and in addition there are many other charges to be met between the producer and consumer, so that the total tax on overland commerce is probably not far from $3,000,000,000 annually.

Very great economies might be effected if any considerable amount of this traffic were carried by water and the average rail haul were reduced. Unfortunately the internal channels are not available, although the government has been struggling with this problem for over forty years and in some instances for nearly a century and a brief analysis of progress seems to be necessary as a guide to future possibilities. For this purpose the best authorities are the official reports of the departments and the records of Congress as to expenditures and results. Numerous organizations have sprung up all over the country [illegible] far greater liberality from the national government [illegible] improvements and the president of the [illegible] ongress who is himself an agressive member [illegible] on Rivers and Harbors, in a recent [illegible]

[illegible] projects have been under way for [illegible] still far from completion. He then [illegible] the shadow of Wall Street under

consideration for 28 years at an estimated cost of only 2,700,000, less than half of which is expended, yet the commerce passing last year was estimated at more than $270,000,000. Over twenty years ago Congress began the opening of the Warrior and Tombigbee rivers to the greatest coal mines on earth. The improvement was estimated to cost $3,000,000; it has subsequently been modified and the estimate doubled, so that it will be many years before it is completed and made available.

The subject of improving the Ohio has been under consideration for more than a century. In 1817–18 the state of Pennsylvania began work to be carried as far as Wheeling. In 1835 Congress applied $550,000 to the river for the 600 miles above the falls at Louisville, and began removing snags and rocks but abandoned it after a few years. The Pennsylvania Railroad organized a corporation to effect its improvement but the government intervened as with other parties and it was not until 1875–6 that the system of movable dams was finally determined upon for this stream and work commenced by the government, in an effort to secure a six-foot stage by such structures, at an estimated cost of some $50,000,000. "It has proceeded with a snail's pace," said Mr. Rausdell. "Out of 52 locks of this system only six have been completed and four others are in process of construction. The project has been changed to one of 9 feet and the estimate increased to $63,000,000. If this gigantic and most meritorous work is continued at the same rate as for the past thirty years it will not be closed at the end of this century."

Long before that date the traffic will be demanding not less than 14-feet, as Chicago is now doing from the lake to the gulf, and as the state of New York demands to hold her trade against the enterprising Canadians who have so wisely enlarged their St. Lawrence canals to over 20 feet and are now proposing the Georgian-Bay-Ottawa route to save still greater distances and costs.

After enormous expenditures in efforts to deepen the Mississippi and frequent changes of plans and personnel there is a possible gain of three feet in the depths below Cairo, secured by the transient method of hydraulic dredging, which does not remove the sediment from the bed but merely shifts it from the shoals for the time

being, requiring a large plant to be maintained for use during low stages only.

The total expenditures of the Government for works of this class since the Civil War have exceeded $545,000,000 which, with the exception of the 20-foot channel in the Great Lakes, has effected no commensurate result and there would appear to be no possible relief in sight under the jurisdiction of the present régime for many years. Certainly no corporate body could hold its own under such an exhibit of expenditures and results. There appears to be but one solution, namely, a return to the early policy under which the waterways of the country were developed by corporations holding state or national charters, when there was little difficulty in securing capital for the local improvements under control of competent local directors, familiar with the needs of their people. The hopelessness of getting the Ohio River open for the greatest manufacturing district in this country, if not in the world, within a reasonable time has stimulated many of Pittsburgh's most enterprising and far-sighted citizens to apply for state and national charters to construct a ship-canal across the lake divide so as to secure a 14-foot water communication with the outer world as soon as practicable. Although no national aid was sought, it took about ten years merely to obtain this consent, but now the project is fairly on its feet, so far as the rights are concerned it should prove to be one of the most valuable and important adjuncts in relieving the engorgment of that section, and be pushed with all possible dispatch to completion. As it is but little more than 100 miles across this lowest divide, the work should be completed in about six years.

In view of the past experience of the improvement of our rivers and harbors under national control it is an undeniable fact that the progress is interminably slow and the results unsatisfactory. The trunk lines are barely improved at all, after more than fifty years of operation, and other isolated improvements are of little or no avail for general transportation purposes. Some of the harbors have been deepened after enormously heavy expenditures made for jetties which did not improve but were auxiliary to dredging, which must be relied upon with increasing expenditure for maintenance. Our own river, the Delaware, has not yet secured a 26-foot channel

at mean low water, nor is the harbor at its mouth a satisfactory refuge for large vessels. The great harbor of New York has but 30-feet at low water and vessels are obliged to await the tides to cross the bar while all the large dredging contractors have withdrawn their plants from the works.

In short it is hopeless to look for relief from this source, for the entire works of the country, and it is essential that the states should again resume their sovereignties and authorize corporations to make the much needed improvements within their borders and also compel the surrender of long time leases where the traffic has been withdrawn, so that manufacturers and others may again receive fuel and raw-material at water rates and with much greater dispatch.

One firm in the Pittsburg district thus saves nearly $1,000,000 annually on its coal bill alone because of the Monongahela River rates by water.

The Internal Improvement Commission of Illinois closes a very strong appeal for the opening of the lakes and gulf waterway in these practical and timely words:

"There is every reason for the State of Illinois to earnestly lead in the promotion of a National Waterway policy, and there is also reason for her to set an example to sister states in a domestic waterway development. When the United States has adopted a systematic policy, we must expect the national function to be restricted to the broad outlines and arteries of a system and that local waterways and ports will be relegated to the states. Meantime it may be worth while to consider whether the state of Illinois, should not undertake the development of the route through the state, receiving from the United States such subsidy as it may choose to give. There may be hidden wisdom in such self-reliance as has marked the state of New York, and it may be that the influence of two such states will be sufficient to lead the Federal government into a National Waterway policy."

The committee might have added that Massachusetts, New York, Pennsylvania and Ohio are also moving along the same lines in the inauguration of their great works independently of government aid and, in some cases, exercising the right to collect tolls from the trade, as on all railroad-transportation routes under corporate control.

Twenty-two years ago it was reported to Congress that "The manifest destiny of the country points unerringly to the emancipation of the waterways as the next great work, not of war but of peace." Why is it not yet accomplished?

THE PRINCETON UNIVERSITY ARCHÆOLOGICAL EXPEDITION TO SYRIA.

By HOWARD CROSBY BUTLER.

(Read April 19, 1907.)

In a paper of this length I can do no more than present a rough outline of the work of the Princeton Expedition to Syria, and dwell upon a few of the more important sections of its work.

The Princeton Expedition of 1904–5 was organized to carry on and supplement the work of the American Expedition to Syria in 1899–1900. Both expeditions comprised four departments, one for surveying and making maps, one for the study of architecture and the other arts, one for Greek and Latin epigraphy and one for Semitic epigraphy. These four departments, with the exception of that for surveying, were in charge of the same four men on both expeditions.

The country explored is more narrowly defined as Central Syria, comprising, in the south, the country far east of the Jordan, the Haurân and the regions south and east of it, namely the ancient Roman Province of Arabia; and, in the north, the country between the river Orontes and the Euphrates, extending as far north as Aleppo; this comprises the ancient Provinces of Syria Prima and Euphratesia. The district between these two regions, comprising Damascus and its vicinity, is better known and less important for archæological research.

These two great tracts, with the exception of the Haurân, are entirely, or for the most part, desert, and are consequently uninhabited except for occasional bands of nomads. They are thus so much the better for the work of archæologists, for the reason that, having been deserted for some thirteen centuries, they have known only natural changes since the beginning of the seventh century. Our explorations were confined almost exclusively to the deserted localities.

The barren wastes of central Syria are not to be thought of as flat and sandy plains; the region is mountainous in most parts, though, as one goes further east, the hills are lower and the country becomes more of a rolling nature. The mountain districts, where the most important remains are found, present a formation not unlike our own Berkshires in Massachusetts, or the mountains of Pennsylvania, but where our own hills are covered with verdure and capped with forests, the hill country of Central Syria is stripped of soil, devoid of verdure, barren of forests and practically waterless. The north is a rocky, mountain waste of limestone, naked to the sky; the south is a rolling sea of black basalt.

This whole region, now sparsely settled or wholly deserted, was, in ancient times, the seat of a highly developed civilization, and thickly populated. There are extensive remains here of cities, large and small, of military posts and excellent roads, all in a remarkable state of preservation, witnessing to the former wealth and impor-
completely exposed for the examination of the explorer, and their
tance of this desert land. These remains are not buried; they stand
state of ruin has been brought about solely by earthquakes.

A hundred questions arise as to how a fertile country could be reduced to the condition of a desert in fifteen hundred years, and a long paper, even a book, might be prepared, attempting to give an explanation. All that I can say now is that there is abundant evidence to prove, first, that the region was thickly settled—twenty large sites, all deserted, can be counted from the top of one high hill; second, that there was soil where now there is none, for the hillsides were terraced up with high walls behind which there is now hardly a cupful of earth; third, that there was water in the stream beds that are now always dry—aqueducts, washing places, bridges and stepping stones show this; fourth, that grapes and olives were extensively grown, for thousands of wine and oil presses are to be found near the deserted towns; and fifth, that wood was abundant, for timbers of large size were too extensively employed in the architecture to permit of their having been imported. Whatever other agencies may have operated to reduce this country to its present state, I believe that the cutting of forests aided and hastened the end.

rts of Syria have been but little explored; few of the s by our expedition appear upon any map. The pioneer e: ; the Marquis de Vogüé, who published maps of two sn ..s of the country, together with one hundred and fifty drawin of architecture, as the result of his journey in 1860–61. Since it time no systematic explorations have been carried on here, though occasional travellers have crossed the region at one point or another. And, though the great high-road between Damascus and Aleppo passes through the northern district, there are important sites within a few miles of it, on either side, that have never been recorded, and probably never visited, by Europeans since the Roman legions were withdrawn. The maps made by our surveyors will add the names of forty ancient towns and a far larger number of smaller sites to the map of Syria, will show the courses of ancient streams and roads, and will thus contribute to Syrian cartography.

A great body of monuments of architecture is being published from the measured drawings, notes and photographs made by our expedition. The earliest building with a definite date belongs to the second century, B. C., though there are undoubtedly some of the structures that are of greater antiquity. From the first century, B. C., to the beginning of the seventh, A. D., there is a great number of definitely dated monuments—buildings of all kinds, temples, palaces, public baths, theatres, fortresses, churches, private residences and tombs of greater or less architectural importance. The great periods represented are the Nabatæan of the first century B.C.–A. D., the Roman of the second and third centuries, A. D., and the Christian of the fourth to the seventh century. The most important of these are the Nabatæan and the Christian, the former as representing the earliest pre-Christian Arabic civilization. The monuments of this period show great dignity of design, grandeur of scale, richness of decoration and fineness of execution, both in the art of building and of carving. This architectural style has been, hitherto, practically unknown. The buildings of the Christian period also present a style of architecture that stands by itself. They illustrate, in well preserved examples, every variety of structure required by a highly civilized people. We have found here the

earliest churches with definitely dated inscriptions upon them—perfectly developed basilicas of the fourth century—public baths as luxurious as those of pagan times, the best preserved private houses of antiquity, not excepting those of Pompeii, and mausoleums of great magnificence.

The architecture of the Nabatæan period, in its earliest monuments, shows no influence of Greek art; its ornament is purely oriental, its profiles unique, and its decorative patterns, either geometrical or taken from the animal or vegetable worlds, are full of oriental feeling. The great temple precinct of Ba'al Shamîn, at a place called Sî', is a wonderful aggregation of structures including, besides the main temple, a colonnaded court (called a *theatron* in an inscription), two other enclosed and paved courts with monumental gateways, two minor temples, and a paved, sacred way.

The Roman period is of great interest for the reason that Syrian builders under Roman domination were far freer in their employment of classical details of construction and of ornament than were the architects of Rome. The pendentive, for instance, the detail of construction by means of which a dome is accommodated to a square substructure, was used in Central Syria in the second and third centuries; it did not appear in Europe until Byzantine times in the sixth century. Classical ornament in the hands of these Syrian architects was infused with a luxuriant grace unknown at Rome. Some of the most stupendous and some of the richest buildings of the Roman Empire were erected in Syria.

The Christian architecture shows absolute independence of Rome on the one side and of Constantinople on the other. It is a curious blending of ancient Greek with oriental motives. The constructive principles are largely Greek, the mouldings are Greek, but the carved ornament is distinctly Asiatic. The Christian period of architecture in Syria did not inaugurate a decline, as it did in Europe, but begins a new fresh and vigorous style that was cut off in its prime by the rise of Mohammedanism.

In addition to our records of these monuments, we here collected many coins, dating from the third century, B. C., to the seventh, A. D., making a series almost complete that covers a period of a thousand years. Many of these coins were minted at Antioch,

Damascus, Bosra or one of the smaller Syrian cities. Smaller collections of glass and terra cotta, and a few specimens of ornaments in gold, silver and bronze, together with beads and seals, serve to indicate the high skill of various craftsmen in Syria 1,500 years ago.

Over a thousand inscriptions in Greek and Latin were copied by the Princeton Expedition. They are chiefly useful in giving dates to the architecture, though a few of them are important historically or linguistically. The number of Semitic inscriptions is smaller, but more important, perhaps, to the science of epigraphy because they are rarer. These embrace inscriptions in Nabatæan, Palmyrene, Syriac, Safaïtic (so-called), Cufic and Arabic.

Combining the study of topography, of architecture with its auxiliary arts, like sculpture, wall painting and mosaic work, and of inscriptions, we should be able to reconstruct the ancient civilization of central Syria at different periods with considerable accuracy.

The reconstruction of an early Christian civilization that was rich and prosperous, even luxurious, is especially interesting; for nowhere else in the world, so far as it is known, are there such abundant remains of the monuments, the utensils, the ornaments the things in daily use that go to make up the unwritten documents of that period, and the inscriptions provide many of the written sort.

The maps, the monuments of architecture, and the inscriptions are to be published together, beginning at once, in a series of fascicules. Each fascicule is to be devoted to an important site or a group of less important sites, and will contain the results of the work of each member of the expedition.

A PRELIMINARY STUDY OF SOME MODERN MICROMETERS

By MARSHALL D. EWELL.

(*Read April 19, 1907.*)

With the advent of the International Bureau of Weights and Measures and our own National Bureau of Standards, each of which has done and is doing a great work in the extension of a uniform and correct system of standards throughout the world, it was to be expected that this uniformity and precision would be exemplified in the stage micrometers manufactured and for sale by makers of scientific instruments in this and other countries. With a view to determining how far this expectation has been realized the writer has collected as many stage micrometers as he conveniently could by purchase from dealers or through the courtesy of friends, and has measured from five to ten spaces on each with great care and herewith presents in part the results of such measurements. The instruments used were an excellent stand made especially for micrometry by the late W. H. Bulloch, a very stable stand made by the Spencer Lens Co., filar micrometers by Zeiss, The Spencer Lens Co., Bausch and Lomb, Zentmayer and others, and a Bausch and Lomb opaque illuminating one-inch objective, a Zeiss A A, and a Leitz No. 3 objective. From five to ten readings were taken at each end of the space measured and the mean taken. The errors in total length of the several spaces measured have not yet been determined, though the observations have been made; and the results here given are the relative errors only or the differences between each designated space and the mean of all the measured spaces. These scales were all, except where otherwise designated, ruled on glass, and in many instances the lines have deteriorated to a considerable extent, though not so as to invalidate the measurements. A few were photographs and one or two had very coarse lines, so coarse as to render them unsuitable for any but low powers.

A + sign indicates that the measured space is too short and a — sign that the space is too long. The unit of measurement is the micron $= \frac{1}{1000}$ mm.

No. I. Glass Micrometer by Bausch and Lomb—Metric scale.

Space Measured	Relative Correction.
First $\frac{1}{10}$ mm	— 1.0 micron.
Second $\frac{1}{10}$ mm	— 1.8 micron.
Third $\frac{1}{10}$ mm	+ 1.0 micron.
Fourth $\frac{1}{10}$ mm	+ 1.0 micron.
Fifth $\frac{1}{10}$ mm	+ 0.8 micron.

No. II. Photograph by Möller.

Space.	Relative Correction.
First $\frac{1}{10}$ mm	0.0 micron.
Second $\frac{1}{10}$ mm	— 0.1 micron.
Third $\frac{1}{10}$ mm	0.0 micron.
Fourth $\frac{1}{10}$ mm	+ 0.2 micron.
Fifth $\frac{1}{10}$ mm	— 0.1 micron.

No. III. Glass Scale ruled on the Engine owned by Cornell University.

Space.	Relative Correction.
First $\frac{1}{10}$ mm	+ 0.2 micron.
Second $\frac{1}{10}$ mm	+ 0.3 micron.
Third $\frac{1}{10}$ mm	0.0 micron.
Fourth $\frac{1}{10}$ mm	0.0 micron.
Fifth $\frac{1}{10}$ mm	— 0.4 micron.

No. IV. Glass Scale by Zentmayer.

Space.	Relative Correction
First $\frac{1}{10}$ mm	— 0.4 micron.
Second $\frac{1}{10}$ mm	— 0.5 micron.
Third $\frac{1}{10}$ mm	0.0 micron.
Fourth $\frac{1}{10}$ mm	+ 0.5 micron.
Fifth $\frac{1}{10}$ mm	+ 0.4 micron.

No. V. Glass Scale by E. Leitz.

Space.	Relative Correction.
First $\frac{1}{10}$ mm	+ 0.1 micron.
Second $\frac{1}{10}$ mm	+ 0.1 micron.
Third $\frac{1}{10}$ mm	+ 0.1 micron.
Fourth $\frac{1}{10}$ mm	— 0.1 micron.
Fifth $\frac{1}{10}$ mm	— 0.2 micron.

No. VI. Glass Scale by Zeiss.

Space.		Relative Correction.
First	$\frac{1}{10}$ mm	—0.2 micron.
Second	$\frac{1}{10}$ mm	+0.2 micron.
Third	$\frac{1}{10}$ mm	+0.7 micron.
Fourth	$\frac{1}{10}$ mm	—0.3 micron.
Fifth	$\frac{1}{10}$ mm	—0.4 micron.

No. VII. Glass Scale by Powell and Leeland.

Space.		Relative Correction.
First	$\frac{1}{10}$ mm	+0.7 micron.
Second	$\frac{1}{10}$ mm	—1.0 micron.
Third	$\frac{1}{10}$ mm	+0.9 micron.
Fourth	$\frac{1}{10}$ mm	—0.5 micron.
Fifth	$\frac{1}{10}$ mm	—0.1 micron.

No. VIII. Glass Scale by Watson.

Space.		Relative Correction.
First	$\frac{1}{10}$ mm	+0.5 micron.
Second	$\frac{1}{10}$ mm	—0.5 micron.
Third	$\frac{1}{10}$ mm	+2.9 micron.
Fourth	$\frac{1}{10}$ mm	—1.7 micron.
Fifth	$\frac{1}{10}$ mm	—1.2 micron.

No. IX. English Scale on Speculum Metal by the late Professor W. A. Rogers.

Space		Relative Correction.
First	$\frac{1}{100}$ inch	+0.4 micron.
Second	$\frac{1}{100}$ inch	—0.6 micron.
Third	$\frac{1}{100}$ inch	—0.3 micron.
Fourth	$\frac{1}{100}$ inch	+0.7 micron.
Fifth	$\frac{1}{100}$ inch	+0.4 micron.
Sixth	$\frac{1}{100}$ inch	—0.8 micron.
Seventh	$\frac{1}{100}$ inch	+0.2 micron.
Eighth	$\frac{1}{100}$ inch	—0.3 micron.
Ninth	$\frac{1}{100}$ inch	+0.1 micron.
Tenth	$\frac{1}{100}$ inch	+0.1 micron.

No. X. Scale on Platinum Iridium, known as "Centimeter A" the Standard of the American Microscopical Society.

Space.		Correction (total).
First	$\frac{1}{10}$ mm	+0.20 micron.
Second	$\frac{1}{10}$ mm	+0.13 micron.
Third	$\frac{1}{10}$ mm	+0.84 micron.
Fourth	$\frac{1}{10}$ mm	—0.60 micron.
Fifth	$\frac{1}{10}$ mm	—0.44 micron.
Sixth	$\frac{1}{10}$ mm	+0.22 micron.
Seventh	$\frac{1}{10}$ mm	—0.14 micron.
Eighth	$\frac{1}{10}$ mm	+0.21 micron.
Ninth	$\frac{1}{10}$ mm	—0.02 micron.
Tenth	$\frac{1}{10}$ mm	+0.18 micron.

The last two scales (IX and X) were ruled from 20 to 25 years ago and are included in this list simply for the purpose of comparison with more recent productions.

The results above given need no comment and show that no advance in precision has been made in the last twenty-five years; indeed the results do not seem to equal those of the former period.

CHICAGO, April 15, 1907.

BIOGRAPHICAL NOTICE OF ALBERT HENRY SMYTH.

By JOSEPH G. ROSENGARTEN.

(Read May 17, 1907.)

Albert Henry Smyth was elected a member of the American Philosophical Society on May 20, 1887. He has been continuously active and useful in it. At the request of the President this brief statement of Professor Smyth's life and work is presented in accordance with our custom.

He was born in Philadelphia on June 18, 1863, and was educated at the George G. Meade Public School, graduated in the June '82 class of the Philadelphia High School, was the valedictorian, and encouraged by the then President Dr. Riche and Professor Taylor, later President, went to Johns Hopkins University, Baltimore, where he received a Master of Arts degree "causa honoris," in 1886,—it was his thesis for his M.A. degree, "Shakespeare's Pericles and Apollonius of Tyre," that rewritten and with large additions, he read before this Society. It is printed in our *Proceedings,* and earned praise for its research on a recondite subject.

His services to this Society were constant and valuable,—he was one of its curators, a member of the Library Committee, represented it at the University of Glasgow on its forty-fifth anniversary, and at the dedication in Paris of the Statue of Franklin, the gift of John H. Harjes, a former resident of this city,—on that occasion too by the appointment of the President of the United States, he was the representative of this country, and his address received the well deserved praise of all his auditors and readers, among them many of the foremost representatives of French eloquence and learning. His addresses at the annual celebration of this Society were always noteworthy, and his last appearance at the general meeting in April of this year, shortly before his untimely death, was warmly welcomed.

His printed works include a sketch of "American Literature,"

published in 1888; "Philadelphia Magazines and Their Contributors," 1892; "Bayard Taylor" in "American Men of Letters" series, 1896; "Shakespeare's Pericles and Apollonius of Tyre," 1898. He was the founder and editor of "Shakesperiana," and was thoroughly imbued with knowledge and love of the great dramatist; he edited "Burke's Letter to a Noble Lord," 1898, and "Pope's Homer's Iliad," 1899, and he was a frequent contributor to magazines and newspapers. His papers were like his popular lectures, for some years, notably about Shakespeare's country, with which he was intimate from frequent pilgrimages, often in the companionship of English men of letters whose friendship and sympathy he enjoyed to a degree rare indeed for a man of his age,—he was as much at home among scholars abroad as at home.

His greatest service to this Society, to the public, and to the fame of our founder, was his ten volume edition of the "Works and Correspondence of Benjamin Franklin," only recently completed. It was a great task and it was carried through with characteristic industry, devotion and critical ability. He was largely inspired to this undertaking by his familiarity with the unrivalled collection of Franklin Papers, over seventy folio volumes, long in the possession of this Society. He atoned for the careless editing of Franklin's Works by Wm. Temple Franklin,—he corrected the errors and restored the real words of Franklin, so frequently altered in Sparks' edition, and he made large and valuable additions to Bigelow's, and that venerable and learned master of Franklin literature generously and heartily commended his young successor's work.

Professor Smyth had in contemplation at the time of his too early death, a popular Life of Franklin, and a Life of Washington, and historical students may well regret that his life was not spared for the accomplishment of these tasks.

Elected in 1886 Professor of English Language and Literature in the Central High School of Philadelphia, he showed remarkable gifts for his task, and won the affection and admiration alike of his colleagues and his pupils. He was constantly helping the students who showed ability, and encouraged them in securing admission to Colleges and Universities, or positions, where many of them gained marked distinction. His popularity with the large body of stu-

dents of the High School was an unusual tribute to his ability, his industry and his broad and generous sympathy with all who shared his love of study.

His "Shakespeare's Pericles and Apollonius of Tyre," a study in Comparative Literature, was the outcome of his Johns Hopkins thesis for his M.A. degree,—recast and expanded, it was read before the American Philosophical Society and was printed in volume thirty-seven of its Proceedings. Reprinted in 1898, it obtained great praise from competent Shakespearean critics at home and abroad, and it is a monument of his learning and critical ability. As he said in reply to some verbal criticism of his frequent use of Shakespearean words and phrases, "A student's nature is soon subdued to what it works in, like the dyer's hand, and I have worked in Shakespeare, steeping myself in his language, until unconsciously I use words and phrases which are, to me, rich in suggestion and association," and he made good use of his mastery of Shakespere.

His great work was his "Writings of Franklin." It was the most effective and important tribute to Franklin's Bicentenary, so well celebrated by this and kindred societies, founded by Franklin and of which he was a member. The ten volumes of Franklin will be a lasting monument of Professor Smyth's industry, research and critical acumen. He unearthed new material at home and abroad to the extent of three hundred and eighty-five letters and forty papers all from Franklin's pen, and not printed by any previous editor; he corrected more than two thousand errors in earlier editions, and restored the text so much altered by Sparks in his mistaken notion of improving Franklin's racy and vigorous English. He found new material in public and private collections, in that recently acquired by the Library of the University of Pennsylvania, as a tribute to its great founder, and in public archives at home and abroad, and in the collections never before consulted by any editor of Franklin's writings. He gave a full account of the Franklin Papers, rescued from neglect and now reverently preserved in the Library of the American Philosophical Society, in the Congressional Library, and in that of the University of Pennsylvania. He gave a bibliography of the printed editions of Franklin's Writings, an analysis of his works, philosophical, politi-

cal and economical, of his satires and bagatelles and of his m farious correspondence. With all his zeal and admiration for Fr lin, and his ability in so many directions, scientific, economic, tical, diplomatic, financial and social, Professor Smyth put a pr limit and restriction upon the reproduction of some of Frank writings, as unfitted for the public of today, and of some p papers wrongly attributed to Franklin or that have lost t value and interest. What he gives shows Franklin at his best, justifies that admiration of him as a man and a philosopher, statesman and a diplomatist, which has made Franklin's fame w wide.

Smyth's Franklin is a work of great and lasting value, it is definitive edition of his writings, for the editor gave to it the results of modern literary canons as to the right way to edit writings of so marked and individual a man as Franklin. In t days of sound historical methods, and in absolute adhesion to fixed rule to give the words of the original text of letters and o writings, Professor Smyth edited Franklin's Writings, wit fidelity that commends his edition to all students. The Index, trying test for all editors, is so complete and exhaustive that inquirer can easily find every item of Franklin's multifarious w ings under subject, place, correspondent or other proper head Professor Smyth unburied the earliest of Franklin's writings, newspaper articles which first revealed his remarkable ability, lowed his many notable publications, illuminated his widely scatt correspondence by judicious notes, compressing in many of then a few lines, the result of many and far reaching investigati He showed critical care alike in exclusion, inclusion and expl tion.

His "Life of Franklin" was all too short, and he had plan to use his large knowledge in the preparation of a Life of Franl free from the restraint of space prescribed by the publishers of "Franklin's Writings," and in it he would have used that intir knowledge of Franklin which he showed in frequent addresses some magazine articles, and in lectures, and particularly in masterly and eloquent oration on the unveiling of the statu Franklin in Paris, the work of a Philadelphia artist, Boyle,

gift of an old resident of Philadelphia, Mr. John H. Harjes,—, on April 27, 1906, in the Trocadero. In the presence of a great audience, Professor Smyth added to his reputation by an oration on Franklin that won the plaudits of the foremost French men gathered together to honor Franklin's memory. That he was chosen by President Roosevelt to make the address of presentation of the Franklin statue, was another tribute to his successful work as the editor of "Franklin's Writings," and brought home to French statesmen and men of letters, the wisdom of the choice made by President Roosevelt, himself an historian well qualified to select the best man.

Professor Smyth had a legion of admirers abroad,—he made almost annual pilgrimages to great historical shrines, and had hosts of friends among the foremost men of letters in Great Britain, in Germany and in France,—he had found sympathetic fellow students in Russia and Poland, in Greece and Italy. He knew Stratford on Avon as he knew Shakespeare, thoroughly, and in London literary clubs, in the great Libraries of London and the English Universities, in Paris and Berlin, he was a familiar visitor, known as a sound student, and welcomed for his many and varied gifts; alike in speech and familiar letters he showed his mastery of English literature, and in his many lectures, his wonderful memory was always helpful to his great gift of eloquence.

As a lecturer in University Extension and Free Library courses and on other occasions, he was heard by thousands, and always with delight and instruction. Under the pressure of the hard work on his ten volume Franklin, he was obliged to curtail his lectures, but in the few given by him during the last winter, he seemed to find relaxation from his Franklin and from his High School work, in delightful lectures on the literature and the literary men and shrines with which he was so familiar. Gifted with a fine presence and an admirable voice, his lectures were a source of infinite pleasure and of much solid instruction.

He gave to the Philosophical Society two capital memorial addresses, one on Dr. Daniel G. Brinton, the other on Henry Phillips, Jr., both scholars and men who had given much of their best work to this Society, and Professor Smyth's tributes were well worthy

of the subjects. His many avocations were always so arranged as to allow him to be a frequent attendant at the meetings of t he Society and its committees; his share in its annual meetings w a an active one, and all who heard his brief, incisive, witty and w el turned addresses in introducing the speakers at its last Annu a Dinner, felt that the death of such a man at the age of forty-thre was indeed a great loss and a lasting sorrow.

That such a man as Albert Smyth, with his vigor and outspok courage, should have enemies was natural, and to their discre rather than to his, for he outlived the attacks made upon him, a showed that there was little or no foundation for them, by t amount and excellence of his work, by the appreciation of his c leagues and pupils at the High School, and by the admiration all who were associated with him in his many fields of activit Life seemed just bringing him the best fruits of his laborio youth,—he was asked by Publishers to undertake more litera work, and with each year this became easier to him, for his lar store of learning was always at his call. One of our great U versities was about to call him to succeed a well recognized lead in history and literature, another was about to confer on him degree of LL.D., and it was thought that he might well have t offer as one of the professorial American representatives in a gre German University. His only doubt was as to giving up teachi and lecturing to enable him to devote himself to authorship,—b the end came suddenly, and now we have only his literary remai and the recollection of a personality that attracted all who ca within its reach. Wit, eloquence, learning, many unusual gifts co centrated in him.

His early youth up to manhood was one of much hardship a struggle, but he was never embittered by his hard experience poverty, nor was he spoiled by the success of his mature yea and the praise that came with it. He never forgot any kindne or help shown to him in his hours of trial,—and he was alwa watchful and helpful of the young men who came under his obse vation,—to them he repaid in abundant measure, all and much mo than all of the help that had benefited him. This was the tru test and proof of the sound manliness of his character, and this

was, quite as much as admiration for his gifts and talents and the good use he made of them, that made him hosts of friends and endeared him to them.

Mr. John Bigelow, the leading authority on Franklin and the man who rescued the original MS. of the famous Autobiography from oblivion, wrote of Professor Smyth's Franklin, "The development of the scientific side of Franklin will be new to the general reader, and the lack of it was perhaps the most conspicuous deficiency of all previous collections," and again on the completion of the work, "Your collection of the literary remains of Franklin constitutes in my judgment one of the most faithful, conscientious and thorough pieces of editorial work with which our literature has been enriched. It places the crown of glory upon the fame of Franklin which no one will ever dare or desire to displace." Such praise from such a man as John Bigelow, himself the foremost exponent of Franklin literature, was indeed grateful.

Of all the many and touching obituary notices of Professor Smyth, the most eloquent was that of William Winter, in the New York Tribune of May fifth, the day after Professor Smyth's death. Winter himself is a Shakespearian scholar, a poet and a man of letters,—he had great sympathy with his younger brother in literature, and it is admirably shown in his biographical and critical sketch. I am sure it will be welcomed by all who knew Professor Smyth and admired his gifts.

"ALBERT HENRY SMYTH.[1]

"One of the noblest minds, one of the gentlest spirits, one of the most auspicious lives in American literature, passes from this world, in the death of Albert Henry Smyth, which befell yesterday morning in Philadelphia. To those who intimately knew him the news of this sudden bereavement brings with it a shock so dreadful as almost to paralyze thought and make any sort of commemorative word impossible. He was in the prime of life: he was in the affluence of enjoyment and hope: he had just completed and published his superb edition of the works of Franklin, together with his Life of that statesman: the echoes of his oratorical triumph at Paris, where he spoke, at the international unveiling of the statue of the great philosopher, had not died away: he had gained an un-

[1] New York *Daily Tribune*, Sunday, May 5, 1907. 2nd Edition.

fading laurel of fame: he was surrounded with affectionate friends: he was richly honored: he was dearly loved: and the pathway to yet more splendid achievements in letters and a yet wider circle and ampler wealth of friends and of honors seemed opening before him, in one long vista of golden promise. His vitality, alike of body and mind, was so extraordinary that no thought of death could ever be associated with him. He seemed formed to lead battalions of thought and to endure forever. His countenance was the beacon light of hope and joy. He animated every mind with which he came in contact. He dissipated all doubts of a glorious future, and he dispelled all dejection. He was a ripe and thorough scholar, and he used his scholarship to cheer the onward march, and not to dispense gloom. He was a natural orator. He possessed a wonderful memory; and it was richly stored with knowledge of the classic literature of all lands. It is doubtful whether, in this respect, his equal exists among American men of letters. He was a reverent student of Shakespeare, and he was entirely competent as a Shakespeare scholar. Among his works there is a most admirable book on "Pericles and Apollonius." He wrote a life of "Bayard Taylor" and a charming book upon the magazines of Philadelphia and the literary movement in that old city—which he so much loved and in which he will be so deeply mourned and so tenderly remembered. His ambition was to excel in learning and to augment the excellence of American literature. He always advocated the right. He abhorred and denounced all the "crank" movements of the day, and all the efforts now in progress to corrupt the pure stream of literature with erotic mush. In one word, he was all that is meant by gentleman. Our society can ill afford to lose such a man as Albert Henry Smyth. Intellectual men find the strife of this world very hard, advocating that which is right, but the best that any thinking worker can do is to follow in his footsteps. The loss of him is unspeakable—but his example remains.

"W. W."

SOME OF THE SUBJECTS OF PROFESSOR SMYTH'S LECTURES.

As characteristic of the width and breadth of his studies, the following list will show how far reaching were his lectures, the fruit of much reading and study.

Franklin; Pepys; Thos. Love Peacock; Modern Polish Literature; Modern Symbolists; American Literature; English Literature; Shakespeare; Shakespeare Readings; Burns and Scott; The Lake School and Country; Nineteenth Century Authors; Literary Memorials of Philadelphia; Irving and Cooper; Hawthorne and Poe; Whittier; The Argonauts of '49; Lowell; The Land of Shakespeare; Shakespeare as a Dramatic Artist, illustrated by an exposition of the construction of the Merchant of Venice and Midsummer Night's Dream, Hamlet, Macbeth and King Lear.

American Literature:—The Colonial Period; The Revolutionary Period; Washington Irving and the New York Writers; Emerson and the awakening of New England; Hawthorne and Poe; Lowell and American Culture; Burns, Scott and the Lake Poets; Bayard Taylor; The Land of Burns and Scott; Wordsworth; Coleridge; Southey, Wilson and De Quincey, Harriet Martineau, the Arnolds, Ruskin and Wm. Watson.

English Literature from Shakespeare to Tennyson; Byron, Shelley, Tennyson, Meredith, Hardy, Kipling.

This is but part of the lecture courses given by Professor Smyth from 1890 to 1907, and not only in Philadelphia and its neighborhood, but in many distant localities.

BIBLIOGRAPHY OF ALBERT HENRY SMYTH.

Bayard Taylor. (American men of letters.) 1896.

Philadelphia Magazines and Their Contributors. 1892.

Shakespeare's Pericles and Apollonius of Tyre, a Study in Comparative Literature. 1898.

Syllabus of a Course of Six Lectures on American Literature. (American Society for the Extension of University Teaching.) University extension lectures, syllabi. 1890–96. Ser. A.

Syllabus of a Course of Six Lectures on Bayard Taylor and his Friends. (American Society for the Extension of University Teaching.) University extension lectures syllabi. 1890–96. Ser. D.

Syllabus of a Course of Six Lectures on English Literature. (American Society for the Extension of University Teaching.) University extension lectures, syllabi. 1890–96. Ser. A.

Obituary Notice of Henry Phillips, Jr. (Proceedings of American Philosophical Soc., Memorial Volume 1, p. 26–35.)
Franklin, Benjamin, Writings. 10 v. 1905–07. Macmillan, N. Y.
American Literature. Philadelphia (Eldredge), 1889.
Pope's Homer's Iliad. 1899. Macmillan, New York.
Burke's Letter to a Noble Lord. 1898. Ginn and Co., Boston.
Syllabus of a course of six lectures on Shakespeare. (American Society for the Extension of University Teaching. University extension lectures, syllabi 1897–98.)
Halliwell-Phillipps Collection: An Address delivered before the Pennsylvania Library Club, January, 1895 in Pennsylvania Library Club occasional papers, No. 2. 1894—to date. (Free Library of Philadelphia.)
Benjamin Franklin:—An oration delivered in Paris April 27, 1906—on "Bi-Centenary of the Birth of Benjamin Franklin." Paris 1906.
Daniel G. Brinton:—An address—delivered before the American Philosophical Society. Jan. 16, 1900. (Proceedings of American Philosophical Society Memorial Vol. 1., pp. 221, etc.)
A "Franklin's Autobiography" with notes was Professor Smyth's last piece of work,—it is to be published in the Gateway Series edited by Henry Van Dyke.

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1907

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CONTENTS.

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VOL. XLVI APRIL–SEPTEMBER, 1907. No. 186.

ON THE TEMPERATURE, SECULAR COOLING AND CONTRACTION OF THE EARTH, AND ON THE THEORY OF EARTHQUAKES HELD BY THE ANCIENTS.

BY T. J. J. SEE, A.M., LT.M., SC.M. (MISSOU.), A.M., PH.D. (BEROL.),
PROFESSOR OF MATHEMATICS, U. S. NAVY, IN CHARGE OF THE NAVAL OBSERVATORY, MARE ISLAND, CALIFORNIA.

(*Read April 20, 1907.*)

I. ON THE TEMPERATURE AND INTERNAL STATE OF THE EARTH.

§ 1. *General Considerations.*

It is well known that Fourier devoted almost the whole of his life to those famous mathematical investigations by which he established the laws for the propagation of heat in solid bodies. His first memoir was communicated to the Institut de France in 1807, but with several subsequent memoirs was allowed to rest in the Archives till 1822, when all were at length published in the celebrated "Théorie Analytique de la Chaleur." Prior to this, however, in the *Bulletin des Sciences par la Société Philomathique de Paris,* avril, 1820, pp. 58–70, there appeared an "Extrait d'un Mémoire sur le Refroidissement séculaire du Globe Terrestre," which contains the earliest detailed statement of the secular cooling of the earth (cf. "Oeuvres de Fourier," edited by Darboux, Tome II., pp. 271–288).

In 1827 Fourier submitted to the Academy of Sciences an additional memoir on the "Temperatures of the Terrestrial Globe and of the Planetary Spaces" (cf. "Oeuvres de Fourier," Tome II., p. 97). He justly remarks that the question of terrestrial temperature is one of the most important and one of the most difficult in the whole range of natural philosophy. This view is still held by physicists to-day, and therefore any inquiry which will materially advance our knowledge of the subject may be welcome to the investigator of the physical problems of our globe. Some of the results here obtained are only approximate; yet they appear to fix fairly accurate limits to the effects which may be ascribed to the movement of heat within the earth, and accordingly may not be wholly without interest to those who are occupied with this difficult subject.

The theory that our earth is undergoing secular cooling, and therefore contracting, is widely spread in the literature of contemporary science; in fact it is made the basis of nearly all current speculations in geology, geophysics, seismology and the related branches of natural philosophy. A theory so widely spread in modern thought and so long current would naturally have great presumptive evidence of truth, and therefore should not be lightly set aside. Yet it often happens that later researches supply criteria which were not available to the earlier investigators; and subsequent workers are required to take account of these advances. This appears to be the situation at the present time in respect to the doctrine of the secular cooling and contraction of the earth, which is currently adopted in so many of the physical sciences.

If it may be shown, when we determine the density, pressure and most probable distribution of temperature within the earth, that no circulation of convection currents has taken place since the globe attained approximately its present dimensions, that the effect of secular cooling is therefore sensible only in the crust, and that no deep-seated contraction has occurred since the earliest geological time, we shall be obliged to conclude that other causes should be found which are adequate to account for the phenomena heretofore explained by the effects of secular cooling. In particular it becomes advisable to subject the doctrine of contraction to a most searching examination and crucial test, in order to ascertain what justification

there is for the premises which have been so long adopted in geology and the related sciences. And to make the results of this criterion as convincing as possible, it becomes necessary to adopt mathematical methods, which inspire the greatest confidence in the final conclusions.

So long as contraction was the only available explanation of earthquakes and mountain formation, and no serious doubt had arisen as to the reality of the assigned cause, it seemed legitimate to adhere to the traditional theories of the physics of the globe. But since a different theory has been developed in the paper on "The Cause of Earthquakes, Mountain Formation and kindred phenomena connected with the Physics of the Earth," which explains the observed phenomena by the effects of water vapor accumulating beneath the earth's crust, and seems to be justified by the harmonious concordance of many facts not otherwise intelligible, it appears necessary to re-examine the foundations of the earlier reasoning.

It is true that the traditional theories were rejected in the paper on the cause of earthquakes, for reasons there assigned; but this step is a highly important one, and as the evidence may not be entirely convincing to others, it seems advisable to give a more connected view of the physical grounds on which the step was taken. The general grounds assigned in the former paper need not be repeated here; it is sufficient to recall that they were based partly on the principles of probability and partly on observed phenomena which appeared to admit of but one interpretation.

The paper on the cause of earthquakes grew out of certain phenomena observed during the great earthquake of San Francisco, and was a natural continuation of the previous work on the "Physical Constitution of the Heavenly Bodies" (cf. *A. N.*, 3992, 4053, 4104; 4152). As a result of these researches on the internal state of the heavenly bodies, the writer reached the conclusion that no convection currents exist within the earth, nor have such currents been possible at any time since the globe developed a density comparable to that which it has at present. It was therefore inferred that the cooling extends only through a very thin crust, and consequently the earth is not now appreciably contracting; nor has the contraction been sensible at any time since the terrestrial spheroid attained

approximately its present dimensions. This conclusion was essentially independent of the encrustation, and rested primarily on the resistance to the supposed convection movements caused by the pressure, which is so great as to make all the matter in the deeper portions of the globe behave as an aeolotropic elastic solid. The matter thus made effectively rigid by pressure, could cool only by conduction, and that process is so excessively slow and the heat transferred by it so small in amount as to render it of little effect in the postulated contraction of the earth.

In the former paper arguments were adduced to show that earthquakes and mountain formation depend principally on the secular leakage of the ocean bottoms, and not on the shrinkage of the globe. An attempt was made to justify this inference by an appeal to the observed lay of the mountains parallel to the sea coasts, and the recognized connection between volcanoes, earthquakes and mountain formation. Mention was also made of the inadequacy of the contraction theory to account for the height of mountains, and their congested distribution; and of various other considerations, such as the observed elevation of the sea coasts by earthquakes and the sinking of the adjacent sea bottom shown by the accompanying seismic sea waves. We shall now examine more at length the physical questions connected with the temperature of the earth, and this will afford a basis for judging of the validity of current theories, as well as of certain conclusions respecting seismological problems reached in the former paper.

§ 2. *The Probable Law of Temperature within the Earth.*

The exact process by which the matter of the earth was gathered together and formed into the spheroid which we now inhabit is quite unknown, and one can conceive of what probably took place only by means of dynamical principles applied to ideal conditions offering by analogy a greater or less degree of probability. In this way well guided imaginative conceptions may enable us to approximate the former physical conditions of our planet. For example, it is not likely that the earth as we now find it was formed very suddenly, all the material being brought together so rapidly that but little of the heat of condensation escaped into space. Neither is it probable that the process of agglomeration was so excessively slow that nearly

all the heat of condensation escaped from the surface by radiation through the atmosphere, thus leaving the slowly-accumulated nucleus within at low temperature. In fact this last view seems to be effectively contradicted by the observed internal heat of the globe; and if heat was retained in the layers just beneath the crust, it must likewise have been accumulated throughout the whole nucleus.

It is much more likely that the agglomeration went on with moderate rapidity, so that the primitive globe in formation cooled about as rapidly as a condensing mass of monatomic gas would do under like conditions. Such a gaseous globe retains a little over one half of the heat of condensation. There are many indications that the sun is such a gaseous globe, and the constitution of Jupiter and Saturn probably is more or less similar. It seems likely that in the formation of the earth the meteorites and finer planetary dust came together at such a rate that the whole new planet thus constituted was made to glow with maximum temperature at the centre, as in the case of a sphere of monatomic gas in a state of equilibrium under its own gravitation. Then as the planet grew in mass by the addition of other meteoritic materials, the pressure augmented also, and eventually became so great as to prevent circulation of convection currents. At length the surface gradually cooled by radiation, grew dense and solid, and thus finally arose the encrusted earth.

It must be remembered that until the earth attained a mass of considerable magnitude, the matter falling into it would not be heated to a very high temperature; for in the early stages of the planet the central temperatures would not be high, nor would the force of gravity be intense enough to condense greatly the central nucleus. But as the mass gradually grew in size, the force of gravity would naturally augment, and the temperature rise accordingly. The rise of temperature would take place throughout the central mass by the condensation of the nucleus under increasing pressure; and the deeper down the matter which condensed, the less of the resulting heat would escape to the surface. Thus when the impacts became more and more violent, under increasing gravity, and the surface temperature was much augmented, the central temperature would rise in nearly the same proportion; so that the central temperature would always be the maximum. Yet it is clear that as

we the surface the fall of temperature would be slow in shells of the nucleus. In fact a considerable sphere at ould have nearly uniform temperature. But the central t could not be lower than that of the enclosing shells; fc so, the heat would flow towards the centre, and when uniformit vas established throughout the nucleus, the flow would start again towards the surface, still leaving the nucleus the hottest part of the sphere.

If some such process be the way in which our globe condensed, it will follow that the temperature is nearly uniform in a central nucleus of considerable size; but towards the surface the fall of temperature would become much more rapid. The curve of temperature thus inferred for the epoch of consolidation corresponds closely to that of an ellipse, in which the semi-axis major represents the radius of the earth, and the semi-axis minor the temperature at the centre. We cannot, to be sure, feel entirely confident that this is the *exact* distribution of temperature within the earth; but it is quite clear that the curve is of this general form, and no doubt an elliptical distribution of temperature will give a close approximation to the truth, which probably is all we can hope for at present. Thus we have established one approximate criterion for the internal distribution of the terrestrial temperature.

The other important criterion is quantitative in character, and is to the effect that one half of the primordial heat of condensation still remains stored up in the globe. This is shown by the following general formula:

$$\frac{Q}{W} = \frac{k-\epsilon}{k-1}, \qquad (1)$$

where Q is the quantity of heat radiated away, W the total amount of work done by gravity, k the ratio of the specific heat of a gas under constant pressure to that under constant volume, and ϵ is the exponent 4/3, in the adiabatic formula $pv^{\frac{4}{3}} = C$ (cf. *A. N.*, 4053, or Ritter's "Auwendungen der Mechanischen Wärmetheorie auf Kosmologische Probleme," Leipzig, 1882).

The temperature attained in the development of the earth must have been very great for all the inner portions, and hence we need not hesitate to adopt the monatomic theory as being most nearly

applicable to these extreme conditions. Accordingly, with $k = 1\ 2/3$, we have $Q/W = 1/2$; and we see that only one half of the heat of condensation has been radiated away, and an equal amount remains stored up in the condensing mass. We must then draw the temperature curve so as to fulfill these two conditions: an elliptical distribution, constructed on an absolute scale such that one half of the primordial heat of condensation is still stored up in the earth.

If it be urged that the earth's matter was not sufficiently heated to be monatomic throughout its whole history, we may recall that when $k = 1.4$, as in common air and most gases, the amount of heat stored up is about 81 per cent. (cf. *A. N.*, 4053); but as this biatomic phase would be of short duration, the extra accumulation during early stages would perhaps about compensate for the loss since surface cooling began. Accordingly a secular accumulation of one half of the primordial heat of condensation would seem to be nearly correct.

In his "Auwendungen der Mechanischen Wärmetheorie auf Kosmologische Probleme" ("Baumgärtner's Buchhandlung," Leipzig, 1882), A. Ritter has established the following formula for the condensation of a gaseous sphere:

$$c_p(\Theta_0 - \Theta_1) = A\eta r \qquad (2)$$

where c_p is the specific heat under constant pressure, 0.2375, $\Theta_1 = 273°$, $A = 1/424$, $r = 6,370,000$ meters, and

$$\eta = \int_0^\rho \left(\frac{g'}{g}\right) d\rho,$$

g being the acceleration of gravity at the surface and g' that at any depth where the radius is ρ. For uniform density

$$\frac{g'}{g} = \frac{\rho}{r},$$

and we have

$$\int_0^r \left(\frac{g'}{g}\right) d\rho = \frac{1}{r}\int_0^r \rho d\rho = \frac{r}{2}, \quad \text{so that} \quad \eta = \tfrac{1}{2}. \qquad (3)$$

By means, however, of a more exact investigation, based on Laplace's law of density, Helmert calculated for Ritter the value $\eta = 0.73$, which is no doubt sufficiently near the truth. Accordingly with these values the above equation (2) gives

$$\Theta_0 = 46{,}455^\circ \text{ C.} = 83{,}619^\circ \text{ Fahr.} \tag{4}$$

Beginning at the centre with a temperature of 83,600° Fahr., we find for the elliptical distribution of temperature within the earth the values shown in the following table. It is found by calculation that this arrangement of the temperature fulfills the two conditions above specified, namely the elliptical distribution, and the following quantitative criterion:

$$\pi(r_i^3 - r_{i-1}^3)\sigma_i\zeta_i^{-1}\Theta_i + \pi(r_{i-1}^3 - r_{i-2}^3)\sigma_{i-1}\zeta_{i-1}^{-1}\Theta_{i-1} + \cdots$$
$$= \pi\sum_{i=1}^{i=i}\left[\left(\frac{r_i}{a}\right)^3 - \left(\frac{r_{i-1}}{a}\right)^3\right]\sigma_i\zeta_i^{-1}\Theta_i = 45{,}000(5.5)\pi. \tag{5}$$

In the second member of this equation the average specific heat of the earth's matter is taken to be 0.2, and the same numerical value is used in evaluating the first member of the expression under the summation sign.

Radius.	Density Water = 1.0.	Pressure in Atmospheres.	Theoretical Rigidity Due to Pressure, that of Nickel Steel = 1.0.	Temperature.
1.0	2.55	1	0.0000	0.0°
0.9	3.75	198,760	0.198760	33500
0.8	4.99	483,691	0.483691	49000
0.7	6.21	842,921	0.842921	59200
0.6	7.38	1,260,966	1.260966	66600
0.5	8.46	1,710,730	1.710730	72500
0.4	9.40	2,152,114	2.152114	77000
0.3	10.12	2,521,620	2.521620	80000
0.2	10.74	2,861,507	2.861507	82500
0.1	11.07	3,050,870	3.050870	83500
0.0	11.21	3,135,727	3.135727	83600

§ 3. *The Laws of Density, Pressure and Theoretical Rigidity Within the Earth.*

Laplace's celebrated law of density for the earth results from an hypothesis introduced into Clairault's general differential equation for the equilibrium of a heterogeneous mass of fluid endowed with a rotatory motion, which permits the integration of the equation in some particular cases, and thus enables the geometer to connect the oblateness of the successive layers of the fluid with the radius of the spheroid, of which the density is supposed to be a function. In default of knowledge Laplace assumed as an hypothesis that the

law of compressibility of the matter, of which before its consolidation the earth consisted, was that the increase of the square of the density is proportional to the increase of the pressure, or $dp = \kappa\sigma d\sigma$, the integrating of which gives (cf. *A. N.*, 3992)

$$\sigma = \frac{Q \sin(qx)}{x} = \frac{\sigma_0 \sin(qx)}{qx}. \tag{6}$$

When calculated numerically the density, pressure and theoretical effective rigidity are found to be as given in the foregoing table (cf. *A. N.*, 3992, 4104).

The hypothesis employed in deducing the rigidity of the earth and other heavenly bodies, namely that the rigidity is proportional to the pressure, has been discussed in *A. N.*, 4152, as follows:

"In ordinary solids such as the metals the property of rigidity is produced by the action of molecular forces which resist deformation. On the other hand the matter within a planet like the earth is really gaseous but above the critical temperature, and therefore in confinement made to behave as an elastic solid wholly by virtue of pressure which brings the molecules within distances at which they again become effective in spite of the high temperature. Thus in cold solids the property of rigidity is due simply to molecular forces which prevent deformation, while for gaseous matter in confinement under such pressure that it acquires the property of an elastic sold, the property of effective rigidity is due wholly to the pressure. In the paper above cited I have therefore taken the rigidity to be directly proportional to the pressure, and ignored all other influences, such as temperature, because by hypothesis the density is assumed to follow Laplace's law, or the monatomic law, in the case of purely gaseous masses, and the temperature is supposed to be conformable to the laws of density.

"This hypothesis seems legitimate, and almost certainly as accurate as Laplace's law and the monatomic law, upon which the calculated pressures depend. Moreover the validity of the hypothesis that the rigidity is proportional to the pressure appears to be confirmed by the close agreement of the numerical values of the earth's rigidity found in this way with those found by the recognized empirical processes depending on the tides and the polar motion."

If this reasoning is justifiable, it becomes possible to calculate the rigidity of the matter at any depth within the earth, and we are enabled to conclude that the yielding of our globe under the influence of tidal forces to which it may be subjected is mainly superficial. The results of these calculations are illustrated by the curves drawn in the accompanying diagram, Fig. *F*.

Observations seem to prove that in transmitting earthquake waves

the globe behaves throughout as a solid; and it must be held the-fore that the matter in confinement acts as an æolotropic elastic sol though if released from pressure it would instantly expand as vap owing to the enormously high temperature.

In the paper on the "Cause of Earthquakes," however, it shown that notwithstanding this general law for the globe as whole, there is a thin layer just beneath the crust which in seism disturbances behaves as a fluid; and the disastrous shaking of t earth is due mainly to the enforced movement of currents in tl layer. Yet this substratum of fluid is under such great pressu beneath the confining crust that the compressed lava transmits eart quake waves almost as if the globe were solid from the surface the centre. Thus even this viscous substratum, under the le pressure of any of the heated matter within the globe, is sufficien rigid to transmit to us faithfully the waves of compression and d tortion which have been communicated to it. It is held that t actual rigidity may be greater than that calculated from the pressu but it can not be less. We are therefore safe in following the ru that the rigidity is everywhere proportional to the pressure, and tl gives us a definite view of the condition of the matter in the diff ent layers.

Mr. R. D. Oldham, F.R.S., has shown that, so far as the prop gation of earthquake waves enables one to judge (*Quarterly Journ of the Geological Society,* August, 1906), the matter of the eartl interior is essentially homogeneous down to within 0.4 of the radi from the centre, where some change appears to take place. Tl probably indicates that the nucleus is a magma of all the elemen with the density and rigidity increasing towards the center, owi to the augmentation of pressure; but the cause of the discontinu about 0.4 of the radius from the center is not yet understood.

On the whole the most remarkable feature of the earth's cons tution is the great increase of pressure towards the center. Tl gives our encrusted planet enormous rigidity and effective streng or tenacity, to withstand any disrupting force. The average pressu or theoretical rigidity of all the *layers* composing the earth's ma is (cf. *A. N.*, 4104):

$$P = \frac{3}{4\pi r^3}\int_0^x p\cdot 4\pi r^2x^2\cdot r dx = \frac{3\cdot 3(\sigma_0 g)^2\cdot r\cdot 4\pi r^3}{4\pi r^3\cdot 2(\sigma_1 g)q^4}\left\{\int_0^x \frac{\sin^2(qx)x^2dx}{x^2}\right.$$

$$\left. - \sin^2 q\int_0^x x^2dx\right\}; \text{ and when } x = 1,$$

$$P = \frac{9(\sigma_0 g)^2 r}{2(\sigma_1 g)q^4}\left\{\frac{q - \sin q\cos q}{2q} - \frac{\sin^2 q}{3}\right\} = 748{,}843 \text{ atmospheres.} \quad (7)$$

And the average rigidity of all the earth's *matter* is:

$$P' = \frac{3}{4\pi r^3}\int_0^x p\cdot 4\pi r^2x^2\cdot r dx\cdot\sigma = \frac{9(\sigma_0 g)^2 r\sigma_0}{2(\sigma_1 g)q^5\sigma_1}\left\{\int_0^x \frac{\sin^3(qx)}{qx}\cdot q dx\right.$$

$$\left. - \frac{\sin^2 q}{q^2}[\sin(qx) - qx\cos(qx)]\right\} = 1{,}028{,}702 \text{ atmospheres.} \quad (8)$$

The rigidity of steel is generally taken to be 808,000 atmospheres, but that of nickel steel is at least 1,000,000. The true rigidity of the earth probably lies between the limits set above, and it seems certain that it exceeds that of common Bessemer steel.

In these calculations no account is taken of the increase of rigidity due to the earth's solid crust, the effect of which is known to be considerable; for even the viscous layers just beneath the crust remain quiescent except when set in motion by the dreadful paroxysms of an earthquake. So difficult is this motion to effect that the throes thereby arising may perceptibly disturb a whole continent, and become sensible to observation throughout the world.

Accordingly if the matter of the interior, in confinement under great pressure, behaves as an æolotropic elastic solid, with a rigidity depending on the pressure and therefore increasing with the depth, it naturally follows that no currents can circulate at great depths; and we see that it obviously is not true, as some geologists have imagined, that liquid lava is extruded from deep down in our globe. Neither is it permissible to suppose, as Professor Chamberlin has done (cf. "Geology," Vol. I., p. 630, and Vol. II., p. 120), that our present volcanoes had their start at a depth of some 1200 to 1500 miles.

It follows from the theory developed in the paper on the cause of earthquakes that the original roots of volcanoes were but little deeper than the explosive forces which give rise to world-shaking

earthquakes. Observations show that this depth seldom exce twenty miles. Not only is there no extrusion of lavas from gr depths at present, but it may also be affirmed with equal certai that there never has been any such deep-seated extrusion since t earliest geological ages, or even since the epoch when our ear had the maximum surface temperature, before the beginning encrustation. We may in fact feel sure that no currents were st ring at any considerable depth even when the surface was wrapp in flaming fluid, long before encrustation and secular cooling h begun. All the steam and other free vapors once within the plan had already been expelled, and formed about it a dense atmospher

Even if the earth had two or three times its present volume, a calculation of the corresponding pressures throughout the mass shows that there would be very little convective movement possible at any considerable depth. It seems to be true therefore that convection has played a very small part in the arrangement of the internal matter of the globe; and one may infer that the denser elements could not settle towards the center, except in the outermost layers. And the most probable view of the matter of the interior is that it is a magma of all the elements, the increase of density towards the center being due to pressure, which is sufficient to cause complete interpenetrability of all substances, especially under the high temperatures there prevailing.

§ 4. *The Hypothesis of Deep Movements Within the Earth Contradicted by Historical and Geological Evidence.*

It is an observed fact, deduced from the study of world-shaking earthquakes, that movements of this character have never been known to originate at greater depth than thirty, or, at the very outside, forty miles. It follows therefore that earthquakes arise either in the crust or in the layer just beneath it. Now if deeper movements of the globe are in progress, some of them would in all probability have been felt within the historical period; for they would not be similar to ordinary world-shaking earthquakes, but would be of much more widespread character, the shock being of more nearly equal intensity throughout the world. No such world-wide disturbance is recorded in the history of the civilized nations, nor is anything transmitted to us by the traditions of barbarous tribes which

may not be explained by ordinary earthquakes. The preservation of the ruins of temples of the classic period alone assures us that no really deep-seated convulsion of the earth has occurred within the last 2,000 or 3,000 years. This general fact seems therefore decidedly adverse to the doctrine of deep-seated movements of the globe.

To be entirely confident, however, that such cataclysms may not occur at very long intervals, it is necessary to consider the indications furnished by the ruins wrought by geological time. The existence of a vast number of more or less unstable natural pinnacles, in the form of columns of weather- and water-worn rock, scattered abundantly in various parts of the earth, all of an age to be reckoned in hundreds of thousands or millions of years, assures us that nothing approaching a deep and powerful convulsion of our planet has taken place within something like a million years. One naturally concludes therefore that such supposed convulsions, which have always been popular in geology, do not really take place at all. The fact that the continents and islands show the preservation of successive species of fossils, arranged in moderately conformable beds, and the recognized proof that the great continents have never greatly changed their places since geological history began, may be said to supply decisive evidence that no deep-seated convulsions, such as Elie de Beaumont and others were accustomed to imagine, ever take place even at periods to be reckoned in millions of years.

All important changes observed in the earth's crust must therefore be ascribed to external agencies, and especially to earthquakes, which originate within forty miles of the surface, and seldom extend to a depth greater than fifteen or twenty miles. Accordingly we may dismiss for the present any further consideration of this problem; but we shall again resume it after we have examined the distribution of temperature and the secular movement of heat deep down in our globe, which will give another proof that the interior of the earth is now and always has been quiescent.

§ 5. *The Secular Propagation of Heat from the Nucleus into the Enclosing Shells would not Give Rise to the Contraction of an Encrusted Planet.*

It was formerly held that the earth was a liquid mass stirred by

convection currents, and thus before encrustation of nearly uniform temperature throughout. This hypothesis lies at the basis of Lord Kelvin's famous paper on the secular cooling of the earth. But in more recent times the conviction has grown that the temperature must have been a maximum at the center, and a minimum at the surface. This law of temperature distribution has been found to be true of all gaseous masses when subjected to strict mathematical inquiry (cf. *A. N.*, 4053, 4104); and it is natural to think that a similar law holds for planets even after they have become encrusted.

Lane first arrived at such views, from his researches on the theory of the sun, in 1869; and subsequent investigators agree that the density, pressure and temperature would be highest at the center (cf. *A. N.*, 4053, 4104). In the paper on the "Physical Constitution of the Heavenly Bodies" (*A. N.*, 4053) reasons are assigned for holding the view that all bodies of considerable size must become monatomic by dissociation of the more complex molecules into atoms at their maximum temperature; and curves are given for the density and temperature corresponding to this condition. It is also shown that after passing through the monatomic condition, encrustation finally results from restricted circulation and surface cooling, which causes great increase of the surface density. If this view be admissible, it will follow that the central temperature is not materially lowered by the cooling incident to the formation of the crust.

We shall therefore be justified in concluding that the monatomic distribution of temperature still holds true approximately in an encrusted planet. But we have already given reasons why the temperature curve, in the case of a body like the earth, which may possibly be of a meteoritic origin, has nearly the form of an ellipse. If we look at the curve for a monatomic distribution of temperature, given in the accompanying plate, right hand upper corner, and imagine that the surface density increases as encrustation advances and the heat flows outward, we shall see that the monatomic curve may easily pass into an ellipse such as was postulated for an encrusted planet. Assuming the earth to be encrusted, and the internal temperature in any section to follow the law of an ellipse changing with the time, the question naturally arises: What would be the changes produced by the steady flow of heat under the conditions assumed by Fourier?

Some prominent geologists believe that the outflow of heat from the nucleus would produce a deep-seated secular contraction such as they imagine might have caused the subsidence of the ocean basins (cf. Chamberlin and Salisbury's "Geology," Vol. I., pp. 563 and 567).

If the initial distribution of temperature in any plane section of the earth corresponds to the ellipse

$$\frac{x^2}{a^2} + \frac{y^2}{a^2(1-e^2)} = 1, \tag{9}$$

the distribution after a sufficient interval τ may be taken to be

$$\frac{x^2}{a'^2} + \frac{y^2}{a'^2(1-e'^2)} = 1. \tag{10}$$

In other words the form and dimensions of the ellipse will change with the time. The two ellipses will intersect at four points, and if they be revolved about the common minor axis, these points of intersection generate circles of no change of temperature; the points are given by the condition

$$x^2\left(\frac{1}{a^2} - \frac{1}{a'^2}\right) + y^2\left(\frac{1}{a^2(1-e^2)} - \frac{1}{a'^2(1-e'^2)}\right) = 0. \tag{11}$$

Here x becomes identical with the radius of the circle about the

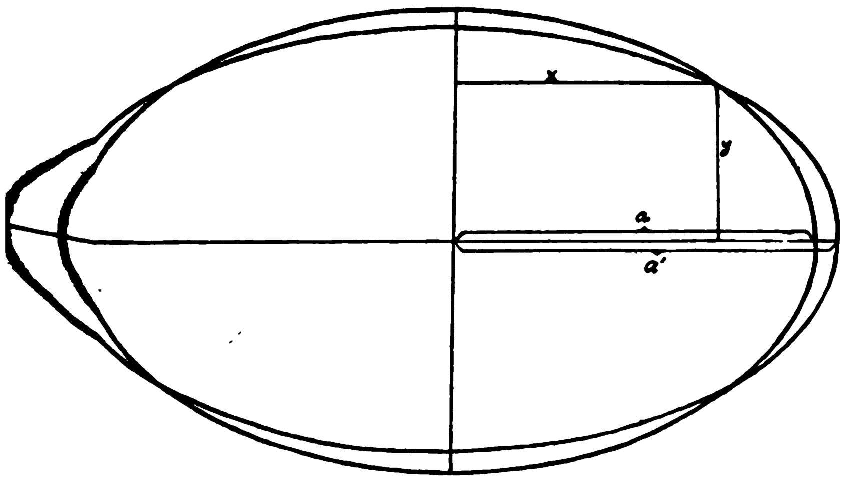


FIG. 1. Section of Ellipsoids.

y-axis, and may be calculated when a, a', e and e' are known, by substituting the value of y in the original equation of the ellipse (9).

Now to show that no change of volume occurs by this propagation of heat from the center outwards, we may observe:

1. That although the major axis of the heat ellipsoid enlarges with the time, the minor axis diminishes, so that except for the slight loss at the surface the volume of the heat ellipsoid remains unchanged, and no heat escapes into outer space; hence there is a change of distribution but not in the total quantity of heat.

2. As this transfer takes place under the confinement of the crust and subjacent layers resting upon the nucleus, the change is necessarily made in such a way as not to do work upon bodies external to the thermodynamic system; nor is work done upon the thermodynamic system itself by external bodies. In either case the constancy of the amount of energy stored up would be altered, which is contrary to the hypothesis.

Any spherical shell $4\pi r^2 dr$, outside of the sphere of no change of temperature, already defined, would have another corresponding shell inside, in which the changes of volume would be equal but of opposite sign to that of the first. Therefore in general we should have

$$4\pi \sum_{i=-i}^{i=+i} r_i^2 dx_i \sigma_i \zeta_i^{-1} d\Theta_i = 0, \qquad (12)$$

where $d\Theta_i$ is the change of temperature experienced by any shell, of density σ_i, and specific heat ζ_i. Hence denoting the variation of the elements of volume by δ, we should have, since the change of volume is directly proportional to the change of temperature,

$$\sum_{i=-i}^{i=+i} \delta(dV_i) = 0. \qquad (13)$$

The conclusions thus briefly indicated may be stated otherwise as follows:

1. The inner shells of the nucleus, having lost heat, might shrink under the pressure to which they are subjected.

2. The outer shells of the nucleus, having gained heat, would have to expand, or the internal tension and latent heat would have to increase. This would be relieved either by bursting the crust, or

by molecular yielding towards the nucleus, which furnished the heat that caused the expansion.

3. Now to burst the crust would be doing external work. Also since the crust is very strong and its substratum deep, the movement of these superincumbent layers would be very difficult, and involve the expenditure of much energy. The easiest mode of adjusting the tension therefore would be by the molecular movement in the outer shells towards the inner shells of the nucleus, which have shrunk by loss of heat, and in such an adjustment the crust would not be disturbed.

4. No surface disturbances traceable to deep nuclear movements have occurred within the historical period, and geological evidence shows the fixity of the continents throughout all geological time. Therefore we may hold that earthquakes arising in the superficial layers are the only causes which have been active in shaping the topography of the surface since the moon was separated from the globe.

5. Since the effect of radial shrinkage in 100 million years is shown to be very small, different estimates ranging from 0.26 to 1.16 miles (cf. Chamberlin and Salisbury's "Geology," Vol. I., p. 573), it seems absolutely certain that progressive diffusion of heat deep down in the earth could produce no sensible effect at the surface.

Speaking of these effects of secular cooling, Chamberlin and Salisbury remark that "they are exceedingly small. Unless there is a very serious error in the estimated rate of thermal loss, or in the coefficients of expansion, cooling would seem to be a very inadequate cause for the shrinkage which the mountain foldings, overthrust faults, and other deformations imply. This inadequacy has been strongly urged by Fisher[1] and by Dutton.[2] In view of the apparent incompetency of external loss of heat, the possibilities of distortion from other causes invite consideration."

Thus the opinion here expressed is favorable to the views developed in the present investigation. Can it then be that the present negation of deep-seated movement since the earliest geological time is without significance in the argument against the theory of the

[1] "Physics of the Earth's Crust," Chap. VIII.
[2] *Penn. Monthly,* Philadelphia, May, 1876.

secular contraction of the globe? Does not the absence of such movement indicate that the effect of such cooling and contraction is wholly inappreciable?

It may be remarked also that the supposed sensible shrinkage is contrary to our hypothesis, based on what appear to be highly probable conditions, namely that no external work is done, but only an interchange effected between the central and peripheral parts of an essentially adiabatic system. On these several grounds therefore it is impossible to entertain the view that the shrinkage or movement of matter deep down in the earth ever exerts a sensible influence at the surface. The detachment of the main body of the matter composing the moon from the vast depression now occupied by the Pacific Ocean, with opposite tidal fragments from the Atlantic, is a much more probable view of the origin of the principal oceanic basins. The levels were no doubt much restored by the plasticity of the material and the subsequent action of the water and atmosphere, but earthquake forces on the other hand have largely counteracted this tendency to uniformity.[1]

§ 6. *Why the Figure of the Earth can never Have Tended to the Tetrahedral Form.*

It is not without considerable surprise that thoughtful students of the physics of the earth have noticed in recent years the recurrence of the suggestion that the original form of the earth was that of a tetrahedron. It is difficult to understand what there is in this improbable conjecture to render it attractive to some minds. But such an hypothesis may no doubt be compared with Kepler's speculations on the regular solids, before the discovery of the true laws of the planetary motions. Kepler's hypothesis was set forth in the *Mysterium Cosmographicum,* 1596, and as given by Whewell in the "History of the Inductive Sciences," Vol. I., p. 416, is as follows:

"The orbit of the earth is a circle; round the sphere to which this circle belongs describe a dodecahedron; the sphere including this will give the orbit of Mars. Round Mars describe a tetrahedron; the circle including this

[1] Since this paper was completed I have received from Professor W. H. Pickering a copy of a suggestive paper, just published in the *Journal of Geology,* in which he deals with the origin of the moon. Many of his views are similar to those here adopted. The suggestion that the moon originated in the Pacific Ocean is due to Rev. O. Fisher, who published it in *Nature,* Jan., 1882, Vol. XXV, p. 243, and again in the second edition of the "Physics of the Earth's Crust," Chap. XXV.

will be the orbit of Jupiter. Describe a cube round Jupiter's orbit; the orbit including this will be the orbit of Saturn. Now inscribe in the earth's orbit an icosahedron; the circle inscribed in it will be the orbit of Venus. Inscribe an octahedron in the orbit of Venus; the circle inscribed in it will be Mercury's orbit. This is the reason of the number of the planets."

In this last line Kepler alludes to the five kinds of polyhedral bodies, known as the only "regular solids," corresponding to the five planets, besides the earth, which were then known.

When we consider these early views of Kepler in the light of the true laws of nature, nothing so much impresses us as the highly artificial character of the suggested cosmical system. But as the ancients had considered the heavens to be made up of spheres of crystal and glass, the contrast with actual nature implied in the system proposed was much less apparent in Kepler's time than in our own, because the heavens were then, through the influence of the Greeks, still viewed largely as a work of art.

The appearance in this late age of the doctrine of a terrestrial tetrahedron, however, is very remarkable. The earth has been known to be a spheroid differing but little from a sphere since 500 B. C., and the law of gravity by which Newton established the cause of the observed form of the globe has been universally recognized for over 220 years. As the earth has always been highly heated within, one can not doubt that the doctrine of fluidity as applied to it is valid. And the form of the surface ought not only to be spheroidal now, but also throughout the whole past history of our globe. This view is likewise confirmed by the figures of the other planets in space, which have been carefully investigated by astronomers ever since the invention of the telescope by Galileo in 1610.

Moreover Tresca's experiments showed that under great pressure all matter behaves as fluid. It is easily shown that a column of the stiffest granite or steel would not stand over five miles high, without crushing and vaporizing at the base. The column would begin to yield when the weight became sufficient to overcome the molecular forces of the material. A solid pyramid would resist crushing to much greater height than a shaft of uniform diameter, but the principle is the same; and no great height would be attained before even a pyramid of the hardest material would begin to spread at the base and flow, from its own weight. Thus there is a limit to the height

at which mountains would stand, but it seems not to be attained on our actual earth. We conclude therefore that even if the earth were as stiff as steel and given the tetrahedral form, the corners would be crushed down and the figure rapidly rounded up under its own attraction, and this deformation would also develop much internal heat. As the earth, assumed to be cold, could not maintain the tetrahedral form when once given it, it certainly would not tend to acquire it with all except a thin crust at high temperature and kept rigid only by pressure. The hypothesis of an original tetrahedral form for the earth must therefore be dismissed as not even a plausible delusion.

§ 7. *The Continental and Oceanic Features of the Terrestrial Spheroid Probably Depend on the Ruptures Produced when the Moon was Formed, and the Smaller Details of the Surface are due to Modifications of the Crust Made by Earthquake Forces Acting in the Underlying Substratum.*

If therefore on the one hand no movements originate deep down in the earth, and the effects of secular cooling at great depths have little or no influence in deforming the surface, while on the other it is shown that there never was a tendency for the earth's mass to assume the tetrahedral form, it follows that the details of the terrestrial spheroid must be explained by forces acting only in the layer just beneath the crust. To suppose that any tendency to a tetrahedral form can have modified the earth's surface is equivalent to the admission that the molecular forces are powerful, in shaping the crust, in comparison with the effects of gravity. Such a view, however, is known to be untenable, because under great pressure all bodies yield and flow like wax, as was found in Tresca's experiments on the hardest substances, to which allusion has already been made (cf. Tresca and St. Vènant, " Sur l'écoulement des corps solides," *Mémoires des Savants Étranges,* Académie des Sciences de Paris, vols. 18 and 20).

The details of the lithosphere must therefore have been shaped by forces acting beneath the crust, and such depressions of level as origially resulted from the detachment of the moon from the earth. That the moon was originally derived from the rupture of the primitive earth-mass seems to be conclusively proved by Professor Sir G. H. Darwin's celebrated researches on this subject. We do not know at what stage the rupture occurred, nor how much larger in volume the

earth then was than it is now; but the separation probably took place in the earlier history of our planet, before encrustation had begun.

The Rev. O. Fisher has calculated that a layer of matter of the density of granite (2.68) no more than 31 miles thick, taken from the outside of our globe, would furnish a mass equivalent to that of the moon. If the earth's radius was then larger than at present, the layer could be correspondingly thinner; and it probably was sensibly larger then than it is now, though certainly not by so much as 25 per cent. As the rupture is supposed to have originated under the disturbing action of the solar tides, the tidally detached mass would not come from the entire hemispheres, but mainly from the tidal protuberances of the two sides, towards and from the sun. When the matter had been detached most of it was at length gathered together and formed into a satellite, but some considerable masses no doubt again fell back to the earth. It seems most likely that the oceanic depressions and continental platforms originated largely in the genesis of the moon. Part of the present distribution of these features on our globe is thus the work of pure chance, but others, as the Pacific, Indian and Atlantic oceans, probably represent the primitive sinks left by the original disruption. The inequalities remaining after certain masses had again united with the earth probably gave the foundations on which the continents and oceans have since been built. It is most unlikely that such a disruption could occur without leaving oceanic basins, and the Pacific and Indian oceans are evidently the area from which the matter of the moon was mainly derived. Instead of a uniform layer 30 or 35 miles deep, a hemispherical meniscus 50 or 100 miles deep at the center, and thinning out at the edges is naturally suggested.

Great modification and leveling of the inequalities of the basins would naturally be effected by the precipitation of some of the detached masses, and by the enormous bodily tides then at work upon the globe, which was no doubt still largely molten or but thinly encrusted. The long continuation of tidal action would largely smooth out the inequalities in the earth's surface, but it seems almost impossible that it could entirely remove the basins left by the detachment of the matter now forming the moon.

This, then, seems to be the most probable origin of the oceanic

basins, and continental platforms; and we probably are not justified in ascribing any sensible part of these inequalities of level to deep seated shrinkage of particular segments. For we have seen that the general shrinkage is quite incapable of producing such large effects, and there is still less reason why certain segments should shrink so much more than others. The average depth of 2.5 miles for the Pacific Ocean can not well be explained by shrinkage. It appears therefore that the great inequalities of the earth's surface resulted from the formative processes involved in the detachment of the moon, while the smaller inequalities such as mountains, high plateaus, and deep ocean troughs and abysses have been produced mainly by earthquakes acting in the layer just beneath the crust. In this way we may legitimately explain all the leading features of the earth's surface; but it is obvious that we cannot give the details involved in the formation of each continent and ocean, because there is no way of retracing this early history of our planet.

II. On the Secular Cooling of the Earth.

extending to infinity in all directions, on the supposition that at an assumed initial epoch the temperature had two different constant values on the two sides of a certain infinite plane; and in finding at the same time the rate of variation of temperature from point to point in the solid. To these ends Fourier has demonstrated the following familiar equation for the linear conduction of heat ("Oeuvres de Fourier," Tome II., p. 273).

$$\frac{d\Theta}{dt} = \kappa \frac{d^2\Theta}{dx^2}. \tag{14}$$

In this equation Θ denotes the temperature for the depth x, at the time t, so that x is the distance of any point from the middle plane, and κ is the conductivity of the solid rock composing the crust, measured in terms of the thermal capacity of the unity of bulk; that is, κ is equal to the number of units of heat which would pass across one square foot of a plate of rock one foot thick in a year, when the two faces of the rock are maintained at temperatures differing by 1° Fahr., the unit of heat being the amount required to raise one cubic foot of the rock through 1° Fahr. By careful experimental observations on several kinds of rock *in situ* Lord Kelvin found that $\kappa = 400$ (cf. "Théorie Analytique de la Chaleur," Chap. lx., § II.; and especially "Le Refroidissement Seculaire du Globe Terrestre," "Oeuvres de Fourier," Tome II., pp. 271–288; Thomson & Tait's "Nat. Phil.," Vol. I., Part II., Appendix D; Fisher's "Physics of the Earth's Crust," second edition, p. 67 et seq.).

If α, β, γ be any arbitary constants whatever, and $f(\alpha, \beta, \gamma)$ a function of these quantities, and x, y, z the coördinates of any point of the infinite solid, the general differential equation for the propagation of heat is

$$\frac{d\Theta}{dt} = \kappa\left(\frac{\partial^2\Theta}{\partial x^2} + \frac{\partial^2\Theta}{\partial y^2} + \frac{\partial^2\Theta}{\partial z^2}\right). \tag{A}$$

And the general integral applicable to the most varied cases, subject to the appropriate surface conditions, indicated by the physical nature of the problem, is

$$\Theta = \int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty}\int_{-\infty}^{+\infty} t^{-\frac{3}{2}} \cdot e^{-\frac{\{(\alpha-x)^2+(\beta-y)^2+(\gamma-z)^2\}}{4t}} \cdot f(\alpha, \beta, \gamma)\, d\alpha\, d\beta\, d\gamma. \tag{B}$$

When the diffusion of heat takes place in every direction the state of the solid is represented by the integral

$$\Theta = \frac{1}{2^3(\pi\kappa t)^{\frac{3}{2}}} \int\int\int e^{-\frac{\{(\alpha-x)^2+(\beta-y)^2+(\gamma-z)^2\}}{4\kappa t}} \cdot f(\alpha, \beta, \gamma) d\alpha d\beta d\gamma. \quad (C)$$

If the initial heat is contained in a determinate portion of the solid mass, one must take account of the limits which include this heated part, and the quantities α, β, γ, which vary under the integral sign, can not take values exceeding these limits (cf. "Théorie Analytique de la Chaleur," Chap. Ix., p. 445). In the case of a symmetrical body like the terrestrial spheroid, it is usual to take the internal distribution of heat to be symmetrical about the center of gravity, which greatly simplifies the general problem. Observations made in many lands indicate that the isothermal surfaces are about equally near the surface at all places, except for the effects of unequal conductivity in the crust; and hence the symmetrical distribution of heat assumed to hold true within the globe seems to be justified. The probable mode of formation of the earth, and the long period during which it has existed, give other grounds for the hypothesis of a symmetrical distribution of the primordial heat about the center of gravity; the unequal temperatures near the surface, due to unequal conductivity in cooling, being confined to a shallow layer of very small extent compared to the globe as a whole. In treating of the heat flowing outward from the center of a symmetrical body like the earth, it thus becomes sufficient to consider the propagation of heat in a single direction normal to the surface. The triple integral is thus reduced to a single integral corresponding to the single variable coördinate, as in the differential equation (14).

The form given the equations by Lord Kelvin and Rev. O. Fisher is but slightly different from that originally used by Fourier, who was occupied with the subject for more than a quarter of a century; but as Lord Kelvin determined the constant of conduction with great accuracy, and also carefully investigated the observed average rate of the increase of temperature with the depth, we shall generally follow his notation, which will also facilitate the comparison of his results with those here obtained.

The rate of variation of the temperature per unit of length perpendicular to the isothermal plane is

$$\frac{d\Theta}{dx} = \frac{V}{\sqrt{\pi\kappa t}} e^{-\frac{x^2}{4\kappa t}}; \tag{15}$$

and the temperature at any point (x, t) in the solid is

$$\Theta = \Theta_0 + \frac{2V}{\sqrt{\pi}} \int_0^{\frac{x}{2\sqrt{\kappa t}}} e^{-z^2} dz. \tag{16}$$

In these equations V = half the difference of the two initial temperature and Θ_0 = their arithmetical mean.

It may easily be proved by differentiation that the expression for Θ satisfies Fourier's equation (14).

When $t = 0$, the expression for Θ, x being positive, becomes

$$\Theta_0 + \frac{2V}{\sqrt{\pi}} \int_0^\infty e^{-z^2} dz = \Theta_0 + \frac{2V}{\sqrt{\pi}} \cdot \tfrac{1}{2}\sqrt{\pi} = \Theta_0 + V. \tag{17}$$

For all negative values of x, $\Theta = \Theta_0 - V$.

By differentiating (16) we obtain $\frac{d\Theta}{dx}$; and it is easy to see that for all values of t, the second term of the right member of this equation has equal positive and negative values for corresponding values of x. Taking Lord Kelvin's experimental value of the conductivity, $\kappa = 400$, equation (15) is reduced to the form

$$\frac{d\Theta}{dx} = \frac{1}{35 \cdot 4} \frac{V}{\sqrt{t}} e^{-\frac{x^2}{1600t}}. \tag{18}$$

Lord Kelvin remarks that if t = 1,000 million years, and $x >$ 3,000,000 feet, the exponential factor becomes less than $e^{-5.6}$, or less than 1/270, which may be neglected as insensible. This indicates that at depths greater than 568 miles the rate of variation of temperature does not become sensible in 1,000 million years. A temperature gradient thus exists only within a thin crust, and the influence of curvature of the surface may be neglected; so that the solution in the case of Fourier's infinite solid becomes immediately applicable to the cooling of the earth.

If we take t = 100 million years from the beginning of the radiation,

$$\frac{d\Theta}{dx} = \frac{1}{35 \cdot 4 \times 10^5} V e^{-\frac{x^2}{1600 \times 10^8}}. \tag{19}$$

… this equation Lord Kelvin found the curve for the rate of v… of temperature in the earth, 100 million years after the i… h, on the hypothesis that the surface temperature was s… wered V degrees, and kept at this figure, so as to produce a d… w of heat from within outward.

He took $V=7000°$ Fahr.

§9. *The Age of the Earth's Consolidation Calculated by the Fourier-Kelvin Method.*

Considering the earth to be a sphere of the same conductivity as average rock, we have for the rate of augmentation of temperature downward

$$\frac{d\Theta}{dx}=\frac{V}{\sqrt{\pi\kappa t}}e^{-\frac{x^2}{4\kappa t}}=\frac{1}{35\cdot 4}\frac{V}{\sqrt{t}}e^{-\frac{x^2}{1600t}}, \qquad (18)$$

κ being 400, when the units are the foot, year, and degree Fahrenheit. Solving this equation for t, and putting $V=7000°$ Fahr., we have

$$t=\left(\frac{51V}{35\cdot 4}\right)^2=101{,}673{,}000 \text{ years.} \qquad (20)$$

This is Lord Kelvin's method of estimating the age of the earth, or the duration since the beginning of the consolidation of the crust, which is supposed to have occurred very soon after the initial epoch.

We have already seen that the assumption of an original uniform temperature for the earth is only a first approximation to the true condition, not justified by a closer examination of the subject. The mathematical theory of the heat distribution in a gaseous globe shows that the temperature increases rapidly towards the center, and hence falls off correspondingly near the surface. Relatively to the average temperature of the whole mass, that of the surface is very low, and that of the center quite high. This is the condition in a gaseous sphere, and it seems certain that it cannot be greatly modified by the surface cooling which leads to encrustation. We have seen that this latter arises mainly from resisted circulation, and retarded supply of heat from the under layers, as the surface density increases. Prior to the beginning of surface cooling the planet passes through a stage of maximum temperature, and heat is both radiated and conducted through to the outer layers; but eventually the resistance to propagation of heat becomes so great that a fall of temperature is inevitable.

In the case of the earth there is excellent reason to conclude that the surface temperature never much exceeded 2000° Fahr.

The experiments of Professors Rücker and Roberts-Austen at the Royal College of Science, London, on basalt or dolerite of Rowley Regis, undertaken at the suggestion of the Rev. O. Fisher, showed that this rock was completely fused at 1688° Fahr. Basalt is a typical rock of the earth's crust, prevalent in nearly all volcanic districts; and it seems probable that a temperature of 2000° Fahr. would therefore not only fuse all the principal rocks of the earth's surface but also reduce many of them to a state of vapor.

The fact that the other planets of our solar system are not at present self-luminous, though the larger masses are known to have high internal temperature, tells against the theory of a very high surface temperature also in the case of the earth. For although we view the other planets at only one stage of their existence, and therefore cannot fully judge of their conditions at other cosmical epochs, yet the absence of self-luminosity when so much heat is known to be stored up within these planets can only indicate that a great lowering of temperature always takes place near the surface, as is also true in a sphere of monatomic gas. Thus it is not probable that even at the maximum the surface temperature of such masses would be very high. There are clear indications that Lord Kelvin's estimate of 7000° Fahr. is much too great; and in all probability we shall not be far wrong in using 2000° as the most acceptable value in all calculations on the secular cooling of the terrestrial globe. The temperature will increase with the depth, but for a shallow layer we may take it to be uniform; the temperature of 2000° then would not correspond exactly to the surface, but rather to the average of a thin sheet forming the boundary of the molten mass. As the outer layer was no doubt agitated from beneath, it would both lack in uniformity of temperature, and also be constantly changing, so that a mean temperature of 2000° Fahr. seems to be the closest approximation we can make to the true conditions.

Using $V = 4000°$ in formula (20), we get $t = 33{,}208{,}850$ years; which is the age of the earth on this hypothesis. When $V = 2500°$ Fahr., we find $t = 12{,}972{,}200$ years. And if $V = 2000°$ Fahr., the result is $t = 8{,}302{,}210$ years, a comparatively short duration. As the

nperature of basalt is less than 1688° Fahr., the smalle
' obviously is to be preferred. Thus the assumed surfac
: of 2000° Fahr. seems sufficiently high, and our mo:
e of the earth calculated in this way is

$$t = \left(\frac{51 V}{35 \cdot 4}\right)^2 = 8,302,210 \text{ years.} \qquad (21$$

gly, we conclude from this Fourier-Kelvin formula that th
our encrusted planet can scarcely exceed 10 million year
ı accords very well with the duration inferred from th
of the sun's heat (cf. *A.N.*, 4053).

The Age of the Earth's Consolidation Calculated by Fisher' hod.

: Rev. O. Fisher has developed another method for calculatin
ıge of the earth which we shall now explain. It is in the mai
endent of Lord Kelvin's procedure based on Fourier's equatio
the rate of increase of temperature downward, and has som
ıntages over it. Fisher's method is treated in Chapter vI., an
in the Appendix, to the second edition of his "Physics of th
ı's Crust." He established the following formulæ:

$$\left.\begin{aligned} V &= 2\mu e^{\mu^2} M \cdot \lambda\left(1 + \frac{y}{k}\right) \\ &= 2\mu e^{\mu^2} M\lambda, \qquad \text{for inert substratum, in which } y = 0. \end{aligned}\right\} \qquad (22$$

$$\beta = \frac{V}{M}\frac{1}{\sqrt{4\kappa t}}, \qquad (23$$

$$k = \mu\sqrt{4\kappa t}, \qquad (24$$

$$M = \int_0^\mu e^{-z^2} dz.$$

In these equations μ is a function differing but little from unity; M is the definite integral $\int_0^\mu e^{-z^2} dz$; κ the coefficient of conductivity taken to be 400, as in Lord Kelvin's work; k is the thickness of the earth's crust; β the surface rate of augmentation of temperature downward; λ is the latent heat of molten rock measured in terms of the amount of heat required to raise one cubic foot of the rock

through 1° Fahr.; and Λ is the latent heat measured in thermal units centigrade, water being the standard substance. In the appendix, p. 20, Fisher shows that Rücker's experiments make $\Lambda = 49.60$, the corresponding value for water at zero centigrade being 79.25. Taking the mean specific heat of average rock at 0.22, he makes $\lambda = 406°$ Fahr., and $V = 1688°$ Fahr. This is the temperature at which basalt is entirely melted. Finally, the quantity y is a function representing the activity of the substratum, and therefore zero when the layer is inert (cf. Chapter vI., p. 73).

Using these values Fisher finds for an inert substratum, that the true values are:

$\mu = 1.007$; $M = 0.7493736$; and the thickness of the crust

$$k = \frac{51 \times 1688 \times 1.007}{5280 \times 0.74937} = 21.91 \text{ miles.} \qquad (25)$$

He concludes that the least thickness of the crust will be $\frac{V}{\beta} = 16.30$ miles, and that the true thickness of the crust will lie between 16.30 and 21.91 miles. If we take $k = 17.5$ miles, which is very near the thickness of the crust indicated by the great earthquake which devastated San Francisco, and apply formula (24) we find for the age of the earth

$$t = \frac{k^2(5280)^2}{\mu^2 4\kappa} = 5{,}262{,}170 \text{ years.}$$

Using $k = 21.91$ miles, in the same formula, Fisher finds

$$t = 8{,}248{,}380 \text{ years.} \qquad (26)$$

This age for the encrustation of the earth seemed to him surprisingly small, and he therefore remarked:

"This is a far shorter period than geological phenomena appear to require, for although it is not possible for them to assign any definite limit to the world's age, we can form some idea of an inferior limit which it must have exceeded. Sir A. Geikie thinks that the stratified rocks alone, which contain organic remains, can not have taken much less than 100 million years for their formation."

The Rev. O. Fisher then proceeds to examine the hypothesis of an energetic substratum, and by this process reaches a greater age for the world. But for reasons pointed out in the previous paper on the cause of earthquakes, the hypothesis of an inert substratum is

obviou proper one. For the substratum is shown to move only under the roes of an earthquake, and no circulatory movement of lava e even just beneath the crust. Hence we adhere to the re tnere obtained, and must consider the significance of the small e of the earth. It will be seen that for a thickness of 22 miles, the age of the earth's consolidation is almost exactly the same as that reached by the use of Lord Kelvin's formula.

1. *Remarkable Agreement of the Times Since the Consolidation of the Globe as Concluded from these Two Methods.*

result found by Lord Kelvin's method rests upon the observed of increase of temperature downward, namely 1° Fahr. for 51 which is about the same as the value used by Fourier nearly a ry ago, and not improved upon by the deep borings made in t years. It also rests upon the assumed surface temperature of Fahr., which probably is comparatively near the truth. Is it an accidental coincidence that with these data one is led by the er-Kelvin formula to an age of 8,302,210 years, while by r's formula, depending on the thickness of the crust essentially d by earthquake phenomena, one finds the almost identical age 8,248,380 years? Moderate variations of the data might derange this excellent agreement somewhat, but probably no change of the constants within admissible limits would produce extreme discordance in the resulting ages of the earth. It seems therefore difficult to escape the conclusion that these figures really approximate the true age of our encrusted planet. At least the period since the consolidation is of the order of ten million years.

Different investigators will naturally form different estimates of the age of the earth as found by the several methods of approximation; but it is difficult to see how the larger values formerly current can be justified by physical research based on the propagation of heat involved in the secular cooling of the globe. The writer has not the geological learning requisite for the use of the methods based on sedimentary rocks and their deposits of organic remains, but it seems very doubtful if these methods can lay claim to even approximate accuracy; and to most minds the conclusions drawn from the physical methods will naturally carry much greater weight.

Some considerations, however, based on the probable average

rate of the elevation of the Andes, taken at only one tenth of an inch a year, or ten inches in a century, seem to show that the age of these mighty mountains need not much exceed three million years. In the case of the mountains west of the Rockies a numerical estimate is not quite so easy, but it is doubtful if anything authorizes an estimate exceeding five million years. In this immense period the whole country west of Laramie may have been raised from the sea; in fact this is indicated by the abundant fossils of Saurians in the beds of Wyoming, as well as by the numerous parallel ranges of mountains in Nevada and California, showing the successive recessions of the sea. One is led therefore to think that after all our consolidated globe may not have an age exceeding eight or ten million years. In comparison with the brevity of human history such periods are almost infinite; and so little is known of the rates of variation of organic species under the unknown conditions of the past, that we may well hesitate before assuming longer periods for the life of our encrusted planet.

In contemplating this result we are again confronted with the question of the cosmical significance of radium. Several years ago when the enthusiasm over the radium discoveries was at its height there were those who admitted a terrestrial history of a thousand million years (cf. Professor Sir G. H. Darwin's presidential address to the British Association at Capetown, 1905). But mysterious as radium still remains, it is doubtful if such a view is generally held to-day. It is a remarkable fact that the more we study radium, the less we seem to really understand the part it plays in cosmical processes. So far at least there is no proof that it exerts any sensible influence, except possibly in chemical transformations.

§ 12. *Some of the Results of the Researches on Radium.*

In spite of the great labor bestowed upon the study of radium by many devoted and enthusiastic investigators, it can hardly be said that we have up to this time any conclusive results as to the cosmical significance of this very wonderful element. The theories of radium disintegration are well known, but not universally accepted. Lord Kelvin is one of those who still ascribe the Sun's heat to the potential energy of the mutual gravitation of its own matter; and he denies that radium plays any appreciable part in solar activity.

utton tried to explain the activity of volcanoes by means outbursts produced by radium, but the distribution of ılong the shores of continents, on islands and in the sea, ıt all break out in the interior of continents, shows that ependence on the oceans, and proves that radium cannot ve cause in producing eruptions. For the experiments of R. J. Strutt have proved that radium is widely distributed rocks of the earth's crust, such as granite; but he found on er hand, that some basalts show scarcely a trace of it. This ot speak favorably for the view that radium is the cause of the nternal heat and volcanic outbreaks. For if radium were the basalts ought to be rich in the element which had caused ulsion of this rock from volcanoes; and since all granite con- abundant radium, volcanoes ought to break out in the interior nents, such as Africa, Australia, North and South America, pe and Asia; but this is contrary to observation. It is not possible therefore to entertain the view that radium has any sensible connection with volcanic activity.

Of late even the terrestrial origin of radium has seemed doubtful, and in *Nature* of February 1, 1907, Professor J. Jolly, of Dublin, has suggested several considerations indicating that radium may come to us from the sun, in the form of infinitessimal corpuscles, expelled principally by the pressure of the sun's light. So far as we can now see this extra-terrestrial source of radium is by no means improbable. But whether this suggestion be verified by time and experience or not, it seems certain that radium in the earth's crust is essentially dormant; at least it plays little part in the physics of planets such as the earth, except perhaps in chemical transformations.

It probably is not without significance that in order to make the theory harmonize with the observed temperature gradient, Strutt attributes radium only to the crust, and not to the interior matter of the earth. If radium comes from the sun, it would lodge in the oceans, and be carried down into the sedimentary and other rocks, as now observed. In the absence of decisive proof we must suspend judgment, but at present one can only say that there is no evidence that radium is an important agency in cosmical processes witnessed upon our globe. For the sake of comparison, however, we give

Strutt's curve of temperature calculated on the hypothesis that radium in the earth's crust is the principal cause of the observed internal heat of the globe. (*Proc. Roy. Soc.*, Vol. 77, 1906.)

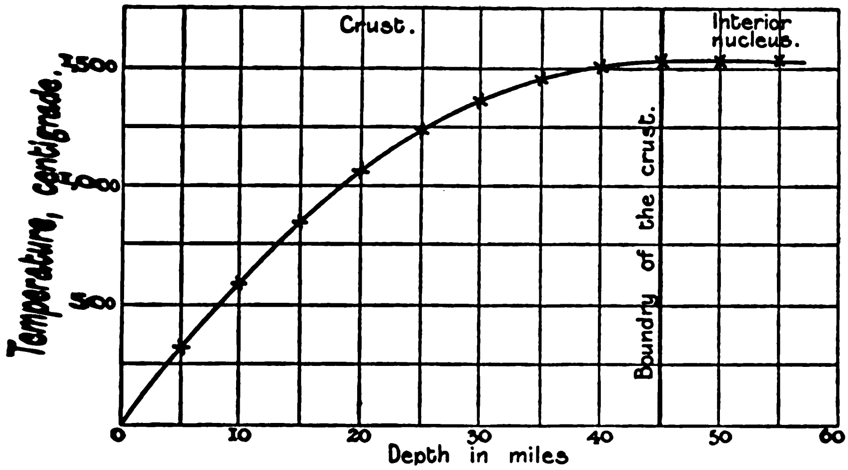


FIG. 2.

III. On the Age of the Consolidation of the Globe and on the Second Approximation to the Law of Temperature Near the Surface.

§ 13. *Consideration of the Twelve Fourier Solutions.*

The methods here employed are those of Fourier, with the constants determined by Lord Kelvin. In view of the great uncertainty heretofore prevailing respecting the age of the earth's consolidation, we have thought it advisable to consider in all twelve cases, namely, three distinct times, of 10,100, and 1000 million years each, and four initial temperatures of 2000°, 4000°, 8000° and 12,000° Fahr. respectively. These twelve solutions are illustrated by the diagrams in the accompanying plate. If the earth had been of uniform temperature throughout, no doubt its actual history would be essentially included in one of the accompanying diagrams.

But we have already seen reasons for holding that the central temperature was very high, and the surface temperature quite low; and moreover there is no doubt that the secular cooling is confined almost entirely to the crust. In considering the age of our earth

therefore we may pass over the diagrams which are based on very high initial temperature. In like manner we may reject those diagrams which are based on such long periods as 1000 million years. For the same reasons a period of 100 million years is much too long. It seems certain that the time since the consolidation of the globe is of the order of 10 million years; and that the surface temperature at the initial epoch did not much exceed 2000° Fahr., and it may never have quite equaled this figure.

But as the actual temperature rises downward, not only in virtue of the surface cooling, but also in accordance with the initial distribution of temperature throughout the globe as a whole, before cooling began, we have to consider the effects of a uniform temperature of say 2000°, and of an independent temperature gradient increasing with the depth. The loss of heat now going on is similar to that depending on the gradient alone—small in amount and very uniform in its rate. Each separate part of this double flow implies rise of temperature downward, and thus we may be sure that the true curve of temperature is steeper than those calculated on the hypothesis of uniform temperature. Thus the rate of augmentation of temperature downward also becomes greater than that calculated in the diagram. The effect then of the original independent gradient is to considerably raise the Fourier temperatures at any depth, and to maintain also a larger rate of augmentation of temperature than the calculated rate.

§ 14. *Approximation to the Actual Law of Temperature near the Surface.*

If we take the Fourier gradient established by secular cooling after 10 million years as giving the original rise of temperature within the earth, before cooling began, which in any case can differ but little from the truth, we may calculate the actual distribution of temperature within the earth's crust as follows:

1. Having computed the rate of augmentation of temperature, and by integration, found the curve of temperature itself for a surface temperature of 2000° and a duration of 10 million years, we calculate likewise the same curves for a duration of 20 million years.

2. The difference between these two sets of curves, one for $t = 20$ million, the other for $t = 10$ million years, when carefully

tabulated, and added algebraically to the ordinates of the original Fourier solution, in which the uniform temperature was 2000°, and $t = 10$ million years, gives very nearly the true curve for the temperature near the surface. This is illustrated by Fig. *D*, in the diagram. The formulæ used are:

For the rate of augmentation of temperature

$$\frac{d\Theta}{dx} = \frac{1}{35.4}\frac{V}{\sqrt{t}}e^{-\frac{x^2}{1600t}}, \qquad \frac{d\Theta'}{dx} = \frac{1}{35.4}\frac{V'}{\sqrt{t+\tau}}e^{-\frac{x^2}{1600(t+\tau)}}, \tag{27}$$

where both t and τ are taken to be each 10 million years, and $V = V'$.

For the curve of temperature we have

$$\left.\begin{aligned} \Theta &= \frac{1}{a}\int_0^{x}\frac{d\Theta}{dx}dx \\ \Theta' &= \frac{1}{a}\int_0^{x}\frac{d\Theta'}{dx}dx \end{aligned}\right\}. \tag{28}$$

$$\Theta_1 = \frac{1}{a}\int_0^{x}\frac{d\Theta}{dx}dx + \frac{1}{a}\left\{\int_0^{x}\frac{d\Theta}{dx}dx - \int_0^{x}\frac{d\Theta'}{dx}dx\right\} = \Theta + (\Theta - \Theta'), \tag{29}$$

in which $a = 2\sqrt{kt}$ (cf. Appendix *D*, Thomson & Tait's "Nat Phil.," Vol. I., part II., p. 477).

More generally the formulæ become

$$\left.\begin{aligned} \frac{d\Theta}{dx} &= \frac{1}{35.4}\frac{V}{\sqrt{t}}e^{-\frac{x^2}{1600t}}, \\ \frac{d\Theta'}{dx} &= \frac{1}{35.4}\frac{V'}{\sqrt{t+\tau_1}}e^{-\frac{x^2}{1600(t+\tau_1)}}, \\ \frac{d\Theta''}{dx} &= \frac{1}{35.4}\frac{V''}{\sqrt{t+\tau_1+\tau_2}}e^{-\frac{x^2}{1600(t+\tau_1+\tau_2)}}, \\ &\vdots \\ \frac{d\Theta^i}{dx} &= \frac{1}{35.4}\frac{V^i}{\sqrt{t+\tau_1+\tau_2+\cdots+\tau_i}}e^{-\frac{x^2}{1600(t+\tau_1+\tau_2+\ldots+\tau_i)}}. \\ &\text{Or when the times are reckoned from arbitrary epochs} \\ \frac{d\Theta^i}{dx} &= \frac{1}{35.4}\frac{V^i \cdot e^{-\frac{x^2}{1600\{t+(\tau_1-t_1)+(\tau_2-t_2)+\ldots+(\tau_i-t_i)\}}}}{\sqrt{t+(\tau_1-t_1)+(\tau_2-t_2)+\cdots+(\tau_i-t_i)}}. \end{aligned}\right\} \tag{30}$$

$$\frac{\Theta}{x}dx + \frac{1}{a}\left\{\int_0^x \frac{d\Theta}{dx}dx - \int_0^x \frac{d\Theta'}{dx}dx\right\} + \frac{1}{a}\left\{\int_0^x \frac{d\Theta'}{dx}dx - \int_0^x \frac{d\Theta''}{dx}dx\right\} + \cdots + \frac{1}{a}\left\{\int_0^x \frac{d\Theta^{i-1}}{dx}dx - \int_0^x \frac{d\Theta^i}{dx}dx\right\}. \quad (31)$$

$$) + \quad -\Theta_1') + (\Theta_2' - \Theta_2'') + (\Theta_3'' - \Theta_3''') + \cdots + (\Theta_i^{i-1} - \Theta_i^i). \quad (32)$$

ıe subscripts on the right corresponding to the i arbitrary epochs.

ın the application of these equations we must remember that this multiple process is valid only for values of x smaller than that corresponding to the maximum of Θ_i. For in Fig. *D*, we see that there is a maximum to the multiple temperature curve, and the true course of it can not be determined beyond this point. The apparent fall of temperature at greater depths indicates the failure of the process. But by taking suitable periods of time, and appropriate values for $V, V', V'', \ldots V^i$, one may approximate the true curve asymptotically near the surface, and carry the determination to any desired depth.

In our present numerical work we have thought it sufficient to take $\tau_1 = 10$ million years, and $V' = V = 2000°$. By carrying this process far enough we may obtain a multiple solution which is almost absolutely rigorous, and it will include all the effects of rising temperature beneath the surface as well as the uniform temperature embraced in the original solution of Fourier. The principal difficulty in extending the method to the propagation of heat at great depths is the uncertainty respecting the original law of temperature within the earth, before encrustation began. But it appears clearly and unmistakably that the true curve of temperature is much steeper than that resulting from the simple Fourier solution. At greater depths the steepness increases more and more, till it finally takes the form of the arc of an ellipse, as already pointed out. The curve is thus concave near the surface, and convex at great depths, so that it has a point of flexure, probably at no very great depth, but the exact location cannot be determined. The simple Fourier solutions always make the curves of temperature convex near the surface, which is a serious defect and introduces discontinuity at greater depths.

It may be noticed that when all the arguments of the times

$\tau_1, \tau_2, \tau_3 \ldots \tau_i$ start from a common epoch $t = 0$, and the functions $V, V', V'', \ldots V^i$ are all equal, the subscripts in the right member of (32) drop out, and the equation reduces to

$$\Theta_i = \Theta + (\Theta - \Theta^i).$$

But in the more general problem the functions $\tau_1, \tau_2, \tau_3, \ldots \tau_i$ date from i chosen epochs, and this gives the means of approximating any curve without change of flexure between $x = 0$, and $x = x$.

§ 15. *Fourier's Methods Adequate for Effecting a Rigorous Solution of the Problem when the Conditions are Known.*

As already remarked the earth is so large and the crust so thin compared to the length of the radius, that the curvature of the surface may be neglected; and the layer of rock considered to extend to infinity in all directions, thus essentially conforming to Fourier's hypothesis of an infinite solid in the form of a flat plane.

Reasons have been assigned for doubting the great age sometimes ascribed to the earth, and it might seem like a waste of effort to draw the curves for the Fourier solutions in the case of such immense periods as 1000 million years; but in view of the great uncertainty heretofore prevailing in regard to the age of the consolidation it appeared advisable to conduct the investigation on the broadest lines. The leading characteristics of these Fourier solutions are shown by the rate of increase of temperature downward, and by the depth at which high temperature is attained. The horizontal scale, representing the depth, is the same in all the curves shown in the diagram; and thus a direct comparison of the effects of the three different periods is possible. In the case of the 1000 million year period the cooling has extended to great depth, more than 445 miles, which exceeds one tenth of the radius; in fact the increase continues downward to about 570 miles, or nearly 0.15 of the radius; but the change of temperature so deep down is excessively slow.

The curves for 100 million years after the initial epoch are naturally much steeper than those just considered, and accord closely with those drawn by Lord Kelvin, who used the same period. In the solution for the interval of 10 million years after the cooling began the curves are naturally very much steeper yet. In fact for this short period the cooling has not yet extended much lower than

40 miles, or about one tenth of that found for the 1000 million year period. The short period thus gives rapid rise of temperature near the surface, while the long periods give slow augmentation of temperature extending to great depths. All the Fourier curves, those for the rate of increase as well as for the temperature, become asymptotic to certain lines, as shown in the diagrams.

We have already considered how to pass from these Fourier solutions to a double solution which will take account of the increase of temperature downward at the initial epoch. This method of superposed or multiple solutions may be applied to all cases, but it has not seemed worth while to consider any case except that with a period of 10 million years and a surface temperature of 2000°. Whether we use the pure Fourier solution, or the compound produced by superposing two solutions of different period, it appears that the actual temperature increases at a nearly uniform rate for a depth of more than 40 miles, after which it is probable that the approximate elliptical law holds true to the center of the planet.

The temperature ellipse is not imagined to extend into the cooled crust, but to begin at the lower boundary of this layer. As we have treated of a superposition of two solutions of different periods, so also we might have compounded three, four or more solutions, with as many independent periods, which would enable us to represent any steady and continuous law of temperature within the earth. If this procedure is justifiable, it will follow that the uniform rise of temperature is nearly maintained for at least a tenth of the radius. Under the circumstances it is not to be hoped that any deviation from the uniform rate of increase near the surface will ever be discovered from experimental measurements of underground temperature. And observations indicating unequal rates at various depths are to be explained by the unequal conductivity of the different layers of the crust, and by fissures filled with hot lava during earthquakes of past geological ages.

From Fig. *D*, in the diagram, we see the principle of the multiple solution illustrated. The difference between the middle and lower curve is the effect of an additional 10 million years. This depression with changed sign should therefore be added to the simple Fourier solution to give the temperature curve under the hypothesis that

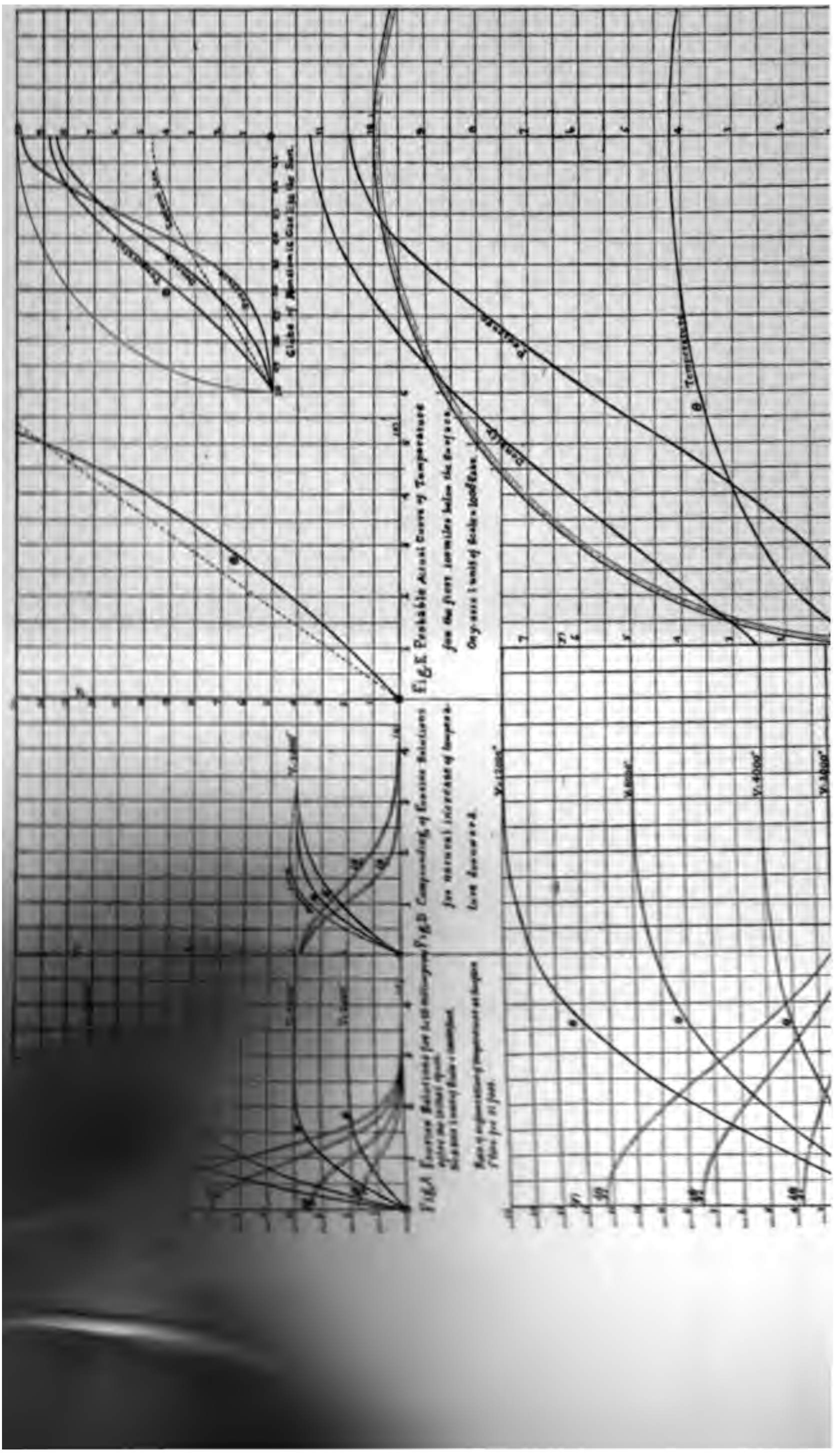
there is both a uniform temperature and an independent gradient equivalent to the effects of 10 million years of cooling.

§ 16. *Various Methods for Determining the Depth to Which Cooling has Extended.*

Owing to the causes already indicated it seems reasonably certain that the cooling of the earth has not extended to any great depth. Moreover the original temperature gradient increasing with the depth still exists, but the flow of heat has changed the form of the curve. It will doubtless strike many as a somewhat remarkable fact that Professor Milne finds from earthquake observations that a fairly abrupt transition in the constitution of the crust occurs at a depth of about 30 miles (Bakerian Lecture, *Proc. Roy. Soc.*, 1906, p. 369). A depth of 45 miles was fixed upon for this transition by the Hon. R. J. Strutt, from certain considerations arising in his researches on radium (*Proc. Roy. Soc.*, Vol. 77, 1906, p. 483). Mr. R. D. Oldham finds that below this layer of crust the material of the globe seems to be fairly uniform until we reach great depth, about 0.4 of the radius from the center, where the change in the rate of propagation of earthquake waves shows that some discontinuity intervenes. Strutt remarks that the matter of the interior can scarcely consist mainly of iron, as has been commonly supposed, because with a thin crust of rock this would make the earth's mean density too great.

The ascertained depth of earthquake shocks and the observed rate of propagation of seismic waves both indicate a thin crust, but the phenomena of wave propagation make the thickness of the crust somewhat greater than that derived from the observed depth of earthquake disturbances. This suggests that earthquakes do not originate entirely beneath the crust, but chiefly in its lower layers. From Milne's results we seem justified in concluding that the cooling has not extended much if any below 40 miles, or 1/100th of the radius. The material below that depth acquires its properties mainly from the pressure to which it is subjected.

We have already considered the extension of Fourier's method which would enable us to approximate the true conditions near the surface; and it only remains to add that at greater depths there is a transition to the elliptical law, which holds approximately throughout the nucleus as a whole. There is obviously some uncertainty about



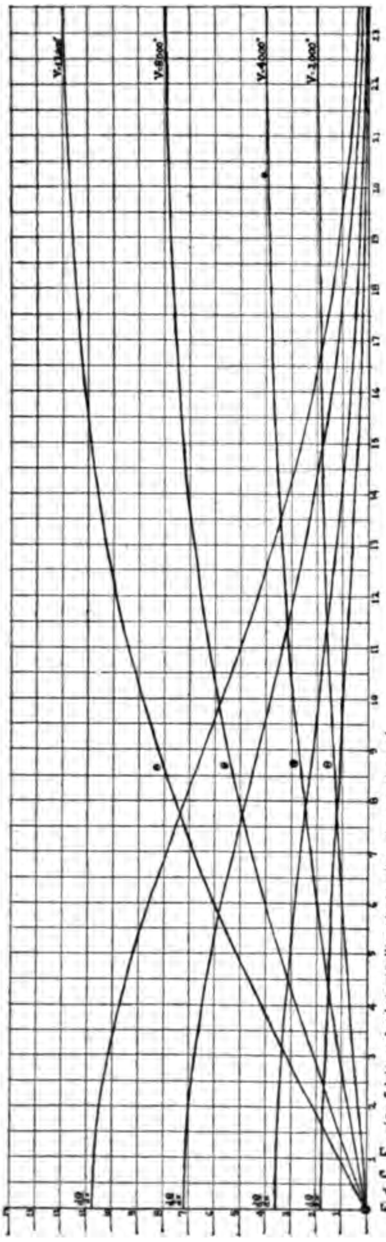


Fig C Fourier Solutions for 1 to 100 million years after the initial epoch.

On x-axis 1 unit of Scale = 100 000 feet.

Rate of augmentation of temperature at Surface 1° Fahr. for 51 feet.

the exact path of the temperature curve where it passes through the layers just beneath the crust. The only condition one can be sure of is that it shall be everywhere continuous and have no change of flexure. It is outwardly concave near the surface, and it must remain so till we reach the arch of the ellipse. In the diagram for the earth's temperature we have drawn this curve according to what seemed to be its most probable course.

It is interesting to observe what the effect of this change of temperature near the surface is on the analysis of Lord Kelvin. We have

$$\frac{d\Theta}{dx} = \frac{V}{\sqrt{\pi\kappa t}} e^{-\frac{x^2}{4\kappa t}}.$$

And it appears that if the temperature increases more rapidly as we go downward, V would be larger for given depth, and the gradient near the surface would be steeper. The same effect could be produced by shortening the time t without changing the value of V. We have adopted this course as the most probable in the treatment of the question given above.

Also since

$$V = \frac{(\Theta - \Theta_0)\sqrt{\pi}}{2\int_0^{\frac{x}{2\sqrt{\kappa t}}} e^{-z^2} dz},$$

V would be changed by changing the limits of the integral, or by modifying the value of Θ. But the integral depends only on x and t, and when these do not change appreciably it is most natural to depart from Fourier's solution by change of Θ.

IV. On the Theory of Earthquakes Held by the Ancients.

§ 17. *On the Inaccessibility of the Views of the Greeks.*

Since Science is the outgrowth of successive revolutions of thought in the course of centuries, it is unfortunate that the views of the Greeks and Romans on many questions are not always accessible to modern readers. It is chiefly by a survey of human thought over long periods that one is enabled to form a clear conception of what has been done in a given subject. Too few students of science

have been able to make an adequate examination of the theory of earthquakes held by the Greeks.

The great multiplicity of subjects in our day, with the resulting unfortunate departure of education from the classic standard, has rendered the original languages of the best ancient authors well-nigh unintelligible to many men of science, because good translations are seldom accessible. One not infrequently meets with surprise even on the part of men of eminence and originality that anything valuable should be found in the writings of the Greeks and Romans.

A masterly grasp of the ancient languages on the part of men of science perhaps is not to be expected, but unfamiliarity with the general spirit of Greek thought is a serious inconvenience, because this defect often leaves the investigator without an adequate view of his own subject. There may thus arise a lack of reverence for the learning of the ancients, because their works are not understood. The poems of Homer and Sophocles, the eloquence of Demosthenes and Cicero, the sculptures of Phidias and Praxiteles, the paintings of Polygnotus and Apelles, the medical knowledge of Hippocrates and Galen, the philosophy of Plato and Aristotle, the astronomical researches of Hipparchus and Ptolemy, the mathematical discoveries of Apollonius and Archimedes—these and many other wonders of antiquity are not calculated to excite a contemptible opinion of the achievements of the Greeks. The perfection of their intellectual labors is attested by the great writers of all subsequent ages, and in modern times by none more amply than by Humboldt and Lyell, who did so much for the foundation of geology.

But while there has been some interest in the theories of the ancients, it has seemed of late years to have become more desultory, which must be ascribed chiefly to the inaccessibility of their works. The English reader possesses the well known translations of Bohn's Classical Library, which often have decided merit; but unfortunately they do not include all the works of Aristotle, the foremost physical philosopher among the Greeks, and the greatest thinker of the ancient times. He included his discussion of earthquakes in the treatise on meteorology, which has never been put into an acessible English translation. Taylor's translation lacks in scholarship, and was limited to fifty copies.

as it may seem at first sight, it is owing principally to sp and characteristic penetration of Aristotle that he ut his discussion of earthquakes in the book which treats phenomena of the air. For he observed the connection be- en earthquakes and volcanoes as clearly as any modern man of could do; and having noticed that in eruptions vapors escape m the earth and diffuse themselves in the atmosphere, he justly concluded that earthquakes are due to the action of pent-up vapors, even when they do not break through and escape to the surface. Could Newton, Laplace, Fourier or any modern investigator reason better than Aristotle has done on this point? In spite of some inevitable errors, due to the early time in which he lived, the penetration which he shows must be indeed a matter of surprise to all thoughtful students of the physics of the earth.

It is obvious that one should not expect from the Greeks and Romans highly finished theories, such as we find in some branches of modern science. If their thought was characterized by general soundness, it may justly excite our wonder. For with all the advantages of the vast learning of our time and the experience of centuries, we cannot claim that the moderns have always been equally fortunate. For example, in speaking of Tycho Brahé, Laplace justly remarks that notwithstanding his great genius for making astronomical observations he had little understanding for physical causes, on which the science of the heavens might be established; and the same remark applies to all except a few of the total number of investigators of subsequent time.

However many working hypothesis may be imagined, it is clear that no real science can be developed until the true physical cause of a phenomenon is discovered. So difficult is the discovery of causes that in speaking of Posidonius, Strabo ("Geog.," Lib. II., Chap. Iv., § 2) says that "he (Posidonius) is much too fond of imitating Aristotle's propensity for diving into *causes,* a subject which we (Stoics) scrupulously avoid, simply because of the extreme darkness in which all *causes* are enveloped." This remark enables one to understand why Aristotle, Posidonius and Archimedes stand so preeminent among the ancients.

Although the Romans had ample political and military instincts,

it is generally recognized that they had very inadequate scientific and philosophic intuition; their philosophers therefore adopted the theories of the Greeks, whose genius they admired. They copied and preserved, but added little to, the treasures of their intellectual masters. Thus Aristotle's explanations are incorporated into the writings of Seneca and Pliny. Aristotle himself gives the history of thought up to his time; and as Strabo was the most important of the later Greek writers on the theory of the world, while Pliny takes the foremost place among corresponding Roman authors, we have in the writings of these three great naturalists a comprehensive digest of the views of antiquity.

Although in his youth Aristotle was trained under Plato, in his later period he composed all his work in a condensed and direct style, without any of the allegorical symbolism so much used by the founder of the Academy. As his death was somewhat premature, at the age of about 63, it is thought by scholars that most all his works were left unfinished. Strabo gives the following account of the vicissitudes of Aristotle's manuscripts:

"The Socratic philosophers, Erastus, Coriscus and Neleus, the son of Coriscus, a disciple of Aristotle, and Theophrastus, were natives of Scepsis. Neleus succeeded to the possession of the library of Theophrastus, which included that of Aristotle; for Aristotle gave his library, and left his school, to Theophrastus. Aristotle was the first person with whom we are acquainted who made a collection of books, and suggested to the kings of Egypt the formation of a library. Theophrastus left his library to Neleus, who carried it to Scepsis, and bequeathed it to some ignorant persons who kept the books locked up, lying in disorder. When the Scepsians understood that the Attalic kings, on whom the city was dependent, were in eager search for books, with which they intended to furnish the library at Pergamus, they hid theirs in an excavation under ground; at length, but not before they had been injured by damp and worms, the descendants of Neleus sold the books of Aristotle and Theophrastus for a large sum of money to Apellicon of Teos. Appellicon was rather a lover of books than a philosopher; when therefore he attempted to restore the parts which had been eaten and corroded by worms, he made alterations in the original text and introduced them into new copies; he moreover supplied the defective parts unskillfully, and published the books full of errors. It was the misfortune of the ancient Peripatetics, those after Theophrastus, that being wholly unprovided with the books of Aristotle, with the exception of a few only, and those chiefly of the exoteric (popular) kind, they were unable to philosophize according to the principles of the system, and merely occupied themselves in elaborate discussions on commonplaces. Their successors, however, from the time

that these books were published, philosophized, and propounded the doctrines of Aristotle more successfully than their predecessors, but were under the necessity of advancing a great deal as probable only, on account of the multitude of errors contained in the copies.

"Even Rome contributed to this increase of errors; for immediately on the death of Apellicon, Sylla, who captured Athens, seized the library of Apellicon. When it was brought to Rome, Tyrannion, the grammarian, who was an admirer of Aristotle, courted the superintendent of the library and obtained the use of it. Some venders of books, also, employed bad scribes and neglected to compare the copies with the original. This happens in the case of other books which are copied for sale both here and at Alexandreia." (Strabo's "Geography," XIII., Cap. 1, § 54; Bohn's Transl., Vol. II., pp. 378–380.)

There are naturally many points in regard to the writings of Aristotle on which scholars are not agreed, but since according to this account the entire works of Aristotle from his own manuscripts were first published at Rome during Strabo's lifetime, the substantial accuracy of the above statement can hardly be questioned. It is gratifying to find that, so far as one can now judge, Aristotle's views on earthquakes do not seem to have suffered any material corruption during the many centuries through which they have been transmitted to us. We may safely infer this from the theory as given by Strabo, soon after the publication of Aristotle's works, and from the theory given by Pliny, who had access to the writings of both Aristotle and Strabo, compared to the original Aristotelian doctrines set forth in the book on "Meteorology," the authenticity of which is unquestioned.

§ 18. *The Theory of Plato.* (*427–347 B. C.*)

As Plato was the teacher of Aristotle, but is not quoted in the account given in the "Meteorology," it seems likely that the expressions in Plato's works may be worthy of notice. The following citations are from Jowett's Translations of Plato's Dialogues.

In the *Phaedo* Plato gives the following discussion between Socrates and Simmias:

"'That,' said Simmias, 'will be enough.'

"'Well, then,' he said, 'my conviction is that the earth is a round body in the center of the heavens, and therefore has no need of air or any similar force as a support, but is kept there and hindered from falling or inclining any way by the equability of the surrounding heaven and by her own equipoise. For that which, being in equipoise, is in the center of that which is

equably diffused, will not incline any way in any degree, but will always remain in the same state and not deviate. And this is my first notion.'

"'Which is surely a correct one,' said Simmias.

"'Also I believe that the earth is very vast, and that we who dwell in the region extending from the river Phasis to the Pillars of Herakles, along the borders of the sea, are just like ants or frogs about a marsh, and inhabit a small portion only, and that many others dwell in many like places. For I should say that in all parts of the earth there are hollows of various forms and sizes, into which the water and the mist and the air collect; and that the true earth is pure and in the pure heaven, in which also are the stars—that is the heaven which is commonly spoken of as the ether, of which this is but the sediment collecting in the hollows of the earth. But we who live in these hollows are deceived into the notion that we are dwelling above on the surface of the earth; which is just as if a creature who was at the bottom of the sea were to fancy that he was on the surface of the water, and that the sea was a heaven through which he saw the sun and the other stars—he having never come to the surface by reason of his feebleness and sluggishness, and having never lifted up his head and seen, nor ever heard from one who had seen, this other region which is so much purer and fairer than his own. Now this is exactly our case: for we are dwelling in a hollow of the earth, and fancy that we are on the surface; and the air we call the heaven, and in this we imagine that the stars move. But this is also owing to our feebleness and sluggishness, which prevent our reaching the surface of the air: for if any man could arrive at the exterior limit, or take the wings of a bird and fly upward, like a fish who puts his head out and sees this world, he would see a world beyond; and, if the nature of man could sustain the sight, he would acknowledge that this was the place of the true heaven and the true light and the true stars. For this earth, and the stones, and the entire region which surrounds us are spoilt and corroded, like the things in the sea which are corroded by the brine; for in the sea too there is hardly any noble or perfect growth, but clefts only, and sand, and an endless slough of mud: and even the shore is not to be compared to the fairer sights of this world. And greater far is the superiority of the other. Now of that upper earth which is under the heaven, I can tell you a charming tale, Simmias, which is well worth hearing.'

"'And we, Socrates,' replied Simmias, 'shall be charmed to listen.'

"'The tale, my friend,' he said, 'is as follows. In the first place, the earth, when looked at from above, is like one of those balls which have leather coverings in twelve pieces, and is of divers colors, of which the colors which painters use on earth are only a sample. But there the whole earth is made up of them, and they are brighter far and clearer than ours; there is a purple of wonderful luster, also the radiance of gold, and the white which is in the earth is whiter than any chalk or snow. Of these and other colors the earth is made up, and they are more in number and fairer than the eye of man has ever seen; and the very hollows (of which I was speaking) filled with air and water are seen like light flashing amid the other colors, and have a color of their own, which gives a sort of unity to the variety of earth. And in this fair region everything that grows—trees, and flowers, and fruits—

is in a like degree fairer than any here; and there are hills, and stones in them in a like degree smoother, and more transparent, and fairer in color than our highly valued emeralds and sardonyxes and jaspers, and other gems, which are but minute fragments of them: for there all the stones are like our precious stones, and fairer still. The reason of this is that they are pure, and not, like our precious stones, infected or corroded by the corrupt briny elements which coagulate among us, and which breed foulness and disease both in earth and stones, as well as in animals and plants. They are the jewels of the upper earth, which also shines with gold and silver and the like, and they are visible to sight and large and abundant and found in every region of the earth, and blessed is he who sees them. And upon the earth are animals and men, some in a middle region, others dwelling about the air as we dwell about the sea; others in islands which the air flows round, near the continent: and in a word, the air is used by them as the water and the sea are by us, and the ether is to them what the air is to us. Moreover, the temperament of their seasons is such that they have no disease, and live much longer than we do, and have sight and hearing and smell, and all the other senses, in far greater perfection, in the same degree that air is purer than water or the ether than air. Also they have temples and sacred places in which the gods really dwell, and they hear their voices and receive their answers, and are conscious of them and hold converse with them, and they see the sun, moon, and stars as they really are, and their other blessedness is of a piece with this.

"'Such is the nature of the whole earth, and of the things which are around the earth; and there are divers regions in the hollows on the face of the globe everywhere, some of them deeper and also wider than that which we inhabit, others deeper and with a narrower opening than ours, and some are shallower and wider; all have numerous perforations, and passages broad and narrow in the interior of the earth, connecting them with one another; and there flows into and out of them, as into basins, a vast tide of water, and huge subterranean streams of perennial rivers, and springs hot and cold, and a great fire, and great rivers of fire, and streams of liquid mud, thin or thick (like the rivers of mud in Sicily, and the lava-streams which follow them), and the regions about which they happen to flow are filled up with them. And there is a sort of swing in the interior of the earth which moves all this up and down. Now the swing is in this wise. There is a chasm which is the vastest of them all, and pierces right through the whole earth; this is that which Homer describes in the words,—

"'Far off, where is the inmost depth beneath the earth'; and which he in other places, and many other poets, have called Tartarus. And the swing is caused by the streams flowing into and out of this chasm, and they each have the nature of the soil through which they flow. And the reason why the streams are always flowing in and out is that the watery element has no bed or bottom, and is surging and swinging up and down, and the surrounding wind and air do the same; they follow the water up and down, hither and thither, over the earth—just as in respiring the air is always in process of inhalation and exhalation; and the wind swinging with the water in and out produces fearful and irresistible blasts: when the waters retire with a

rush into the lower parts of the earth, as they are called, they flow through the earth into those regions, and fill them up as with the alternate motion of a pump, and then when they leave those regions and rush back hither, they again fill the hollows here, and when these are filled, flow through subterranean channels and find their way to their several places, forming seas, and lakes, and rivers, and springs. Thence they again enter the earth, some of them making a long circuit into many lands, others going to few places and those not distant, and again fall into Tartarus, some at a point a good deal lower than that at which they rose, and others not much lower, but all in some degree lower than the point of issue. And some burst forth again on the opposite side, and some on the same side, and some wind round the earth with one or many folds, like the coils of a serpent, and descend as far as they can, but always return and fall into the lake. The rivers on either side can descend only to the center and no further, for to the rivers on both sides the opposite side is a precipice.

"'Now these rivers are many, and mighty, and diverse, and there are four principal ones, of which the greatest and outermost is that called Oceanus, which flows round the earth in a circle; and in the opposite direction flows Acheron, which passes under the earth through desert places, into the Acherusian lake: this is the lake to the shores of which the souls of the many go when they are dead, and after waiting an appointed time, which is to some a longer and to some a shorter time, they are sent back again to be born as animals. The third river rises between the two, and near the place of rising pours into a vast region of fire, and forms a lake larger than the Mediterranean Sea, boiling with water and mud; and proceeding muddy and turbid, and winding about the earth, comes among other places, to the extremities of the Acherusian lake, but mingles not with the waters of the lake, and after making many coils about the earth plunges into Tartarus at a deeper level. This is that Pyriphlegethon, as the stream is called, which throws up jets of fire in all sorts of places. The fourth river goes out on the opposite side, and falls first of all into a wild and savage region, which is all of a dark-blue color, like lapis lazuli; and this is that river which is called the Stygian river, and falls into and forms the lake Styx, and after falling into the lake and receiving strange powers in the waters, passes under the earth, winding round in the opposite direction to Pyriphlegethon, and meeting in the Acherusian lake from the opposite side. And the water of this river too mingles with no other, but flows round in a circle and falls into Tartarus over against Pyriphlegethon; and the name of this river, as the poets say, is Cocytus.'"

In the *Timeus* Plato represents a priest of Sais in Egypt as saying to Solon:

"'There have been and will be again, many destructions of mankind arising out of many causes; the greatest have been brought about by the agencies of fire and water, and other lesser ones by innumerable other causes. There is a story which even you have preserved, that once upon a time Phaethon, the son of Helios, having yoked the steeds of his father's chariot, because he was not able to drive them in the path of his father, burnt up all that was

upon the earth, and was himself destroyed by a thunderbolt. Now this ha the form of a myth but really signifies a declination of the bodies moving i the heavens around the earth, and a great conflagration of things upon th earth, which recurs after long intervals; at such times those who live upo the mountains and in dry and lofty places are more liable to destructio than those who dwell by rivers or on the seashore. And from this calamit the Nile, who is our never failing saviour, delivers and preserves us. Whe on the other hand, the gods purge the earth with a deluge of water, th survivors in your country are herdsmen and shepherds who dwell in th mountains, but those who, like you, live in cities are carried by the river into the sea. . . .'"

Plato continues the discourse and finally tells of the sinking of th islands of Atlantis by an earthquake:

"'Many great and wonderful deeds are recorded of your state in ou histories. But one of them exceeds all the rest in greatness and valour. Fo these histories tell of a mighty power which unprovoked made an expeditio against the whole of Europe and Asia, and to which your city put an end This power came forth out of the Atlantic Ocean, for in those days th Atlantic was navigable; and there was an island situated in front of the strait which are by you called the pillars of Herakles; the island was larger tha Libya and Asia put together, and was the way to other islands, and fron these you might pass to the whole of the opposite continent which surround the true ocean; for this sea which is within the Straits of Herakles is onl a harbor, having a narrow entrance, but that other is a real sea, and th surrounding land may be most truly called a boundless continent. Now in this island of Atlantis there was a great and wonderful empire which ha rule over the whole island and several others, and over parts of the conti nent, and, furthermore, the men of Atlantis had subjected the parts of Liby within the columns of Herakles as far as Egypt, and of Europe as far a Tyrrhenia. This vast power, gathered into one, endeavored to subdue at a blow our country and yours and the whole of the region within the straits and then, Solon, your country shone forth, in the excellence of her virtu and strength, among all mankind. She was preeminent in courage and mili tary skill, and was the leader of the Hellenes.

"'And when the rest fell off from her, being compelled to stand alon after having undergone the very extremity of danger, she defeated an triumphed over the invaders, and preserved from slavery those who wer not yet [illegible]ed, and generously liberated all the rest of us who dwel within the [illegible]. But afterwards there occurred violent earthquakes an floods, [illegible] single day and night of misfortune all your warlike men i [illegible] into the earth, and the island of Atlantis in like manner dis [illegible] depths of the sea. For which reason the sea in those part [illegible]ecause there is a shoal of mud in the way; and this was cause [illegible]ence of the island.'"

[illegible]ount clearly shows that Plato ascribed to earthquakes th [illegible] cause the submergence of land beneath the sea. As h [illegible] excellent geologist for his time, he no doubt accepted als

the doctrine of the upheaval of the land by earthquakes. Aristotle distinctly states that these calamities are forgotten and lost from memory by the migrations of peoples and the ravages of time, and Plato clearly holds the same view.

§ 19. *The Theory of Aristotle* (384–322 B. C.).

The English translation given below is based on the Greek Text employed in the Tauchnitz edition of the works of Aristotle. The "Meteorology" is acknowledged to be a genuine production of the Stageirite, and the chief difficulty in translating it consists in the peculiar terminology and terseness of style used in this probably unfinished work. After the present translation was outlined the Rev. Theodore F. Burnham, M.A., very kindly read it and offered a number of valuable suggestions based on his extensive knowledge of Greek. Professor Edward B. Clapp, head of the Department of Greek in the University of California, also favored the translator with valuable criticisms, and very kindly supplied a copy of the scholarly French Translation by Barthelemy Saint-Hilaire, for the purpose of comparison in the final revision. As Aristotle's style is somewhat unique and peculiar to himself, this was felt to be important as a necessary precaution to ensure accuracy, especially where the language of the author is unduly condensed or incomplete, and therefore not easily interpreted.

Aristotle held that the air is produced from the evaporation of water ("Meteor.," Lib. I., Chap. 3) by the fire inside and outside the earth, and says that the air is a kind of vapor. He recognized that air could be heated by rapid and violent motion, and as arranged his adopted system of the world was made up of a lithosphere, a hydrosphere, an atmosphere, a pyrosphere and then beyond all the sphere of ether; certain interchanges took place between these divisions of the world.[1] Aristotle uses separate words for the various

[1] Among the many other points discussed by Aristotle we may mention the following:

1. The primitive fluidity of the globe. He holds, with Thales, that both the earth and sea were originally liquid; that a part was dried up by the sun. Indeed the wise men held that the sea was diminishing in volume by gradual desiccation, but Aristotle does not seem to hold this view. (Lib. II., Cap. 1, § 1–4)

2. The earth is spherical, not large, fixed in the center of the universe, causes night by its shadow in space, and also eclipses of the moon, the atmosphere being confined to this perishable sublunar sphere, as in the Almagest of Ptolemy, who often follows Aristotle.

phenomena connected with exhalations and vapors; [illegible] for a blast of wind or vapor; [illegible] is exhalation; [illegible] for wind. The translation of [illegible], meaning literally a breath, is very difficult, and seems best rendered by the phrase blast of wind or vapor, which seems to convey Aristotle's true meaning.

In the "Meteorology," Lib. I., Cap. [illegible], the following interesting passage occurs:

"It is not true, as they say, that the comet only appears in the north, even at the same time when the sun is in the summer tropic; for indeed the great comet which was seen at the time of the earthquake in Achaia, and the inundation of the sea wave, took its course from the setting of the equinoctial; and several others have been observed towards the south."

Again we read:

"The water which falls in rains drains away and nearly all flows into the earth. But there is in the earth a large amount of fire, and a great heat [illegible]. (Lib. II., Cap. 4.)

Also:

"Thus when it rains, since the earth is dried by the heat which is in it and by that which has escaped above, an exhalation of vapor develops. This is the body of the wind [illegible]. And when this secretion is going out the winds blow. But when they cease because the heat, which is always secreted, is borne to the upper regions, the steam [illegible] being cooled, condenses and becomes water; and when the clouds are collected in one place and the surrounding cold penetrates them, water is formed and cools the dry exhalation" [illegible]. (Lib. II., Cap. 4.)

Aristotle's Theory of Earthquakes is as follows ("Meteorology," Lib. II., Cap. vii.):

"After these things (in relation to the winds) it is necessary to speak with reference to an earthquake and movement of the earth; for the cause of the phenomenon is closely connected with this (theory of the winds).

"Up to the present time there are three explanations of these phenomena from three different authorities: Anaxagoras the Clazomenian, and before him Anaximenes the Milesian have each discussed them, and subsequently to these Democritus the Abderite.

"Now Anaxagoras holds that the ether when generated is naturally borne upward, and falling into the depths of the earth below, and the cavities, shakes it; and the upper parts of the earth in consequence of the rains are pressed together; and freely admitting that by its nature the earth is everywhere equally porous, he holds that the sphere has in its totality both an elevation and a base, the elevation being the part which we happen to inhabit and the base the other part.

"With reference to this subject then perhaps we ought to say nothing

simply because it is too superficially proved. To understand the elevation and base in such a way that all the bodies which have weight would not at every place be borne to the earth, while the light bodies and the fire tend upward, is indeed most absurd; for this is going contrary to the evidence of our senses, which show us that the horizon of the habitable world, so far as we know it, varies constantly according to the extent which we ourselves change place, the earth being convex and spherical. To say that on account of its mass it remains in the air, and to maintain that the trembling of the earth arises when it is smitten from below upwards in its totality, is not less strange. Moreover, in these considerations, Anaxagoras takes no account of some circumstances which accompany earthquakes; for not all lands, nor all seasons participate in this commotion, by chance and indiscriminately.

"Democritus indeed holds that the matter of the earth is full of water, and receiving much other water from the rain storms, it is moved by this; but this arises more from the inability to hold (the water) in the yawning cavities, which, breaking forth violently, causes the shaking of the earth; and the ground being dry and drawing forth into the empty places water escaping from the reservoirs, gives rise to motion of sudden agitation.

"Anaximenes, on the other hand, holds that when moistened and afterwards dried out the earth is shattered to pieces, and is shaken from the sinking in of fragments of the hills; from which also arises the earthquakes in the dry, and likewise in the wet, seasons; for in droughts, just as is said, the dry ground is cracked open, and the overmoist earth, produced by the absorption of the waters, subsides. If that happens which is agreeable to the theory of Anaximenes one should observe in many places the earth caving in. Yet by what cause the phenomenon arises in certain places, no one opinion carries extreme weight of authority relatively to others; nevertheless such a claim was put forth.

"This explanation supposes necessarily that earthquakes always become less and less powerful, and finally cease to vibrate. That which settles down ought to do so naturally. Consequently if this is impossible, it is very evident that it can not be the true cause of the phenomenon.

"CAP. VIII.

"But since it manifestly is a necessity, that exhalation of vapor should be produced all the time, both from the moisture and from the dryness, as we have said in what precedes, it is likewise necessary that from these antecedents earthquakes should be produced; for in itself the earth is dry, yet on account of the rains, acquires in its interior much moisture; so that having been warmed by the sun, and the internal fire, largely indeed from without, but also largely from within, the blast of vapor is developed; and this blast when it sometimes escapes externally flows in a continuous manner; and likewise sometimes when it escapes within the earth; and then again it is scattered. If then this can not take place otherwise, we must consider what among all these bodies, is the most capable of producing the motion; this is necessarily that which naturally goes fartherest, and is most violent, but especially of this latter nature.

"Now the most violent is of necessity that which moves the most rapidly;

for it communicates violence principally through the rapid speed. But the body which goes fartherest, is that which most easily traverses all things; and it is the lightest body which is able to do this. Consequently since the nature of the air itself is the lightest, it is the blast of wind which most powerfully moves all bodies; for the fire, whenever accompanied by a blast of wind, produces a flame, and it is borne rapidly. Therefore is it neither the water, nor the earth which is the cause of the shaking, but the blast of wind, whenever the evaporation without may have again accumulated within (the earth). Hence in a calm arise the most and the largest earthquakes; for the exhalation being naturally continuous it follows that in general it will develop with the very first agitation of the cause. Consequently either from within the earth all at once, or from without by a violent impulse, the whole body of vapor rushes en mass. But that some earthquakes should be produced, coincident with a dominant blast of wind is not strange; for we sometimes see several winds blowing together; from this circumstance, whenever one strikes the earth more violently than the other while the blast is blowing an earthquake takes place. But these give rise to tremors of inferior magnitude, because their principle and cause are separated.

"Now the larger number and greatest earthquakes occur by night; those of the day about noon; for the calmest time of the day in general is at noon; for the sun then, when of the greatest power, confines the vapors to the earth; and is most powerful about mid-day; and the nights of these days are calmest, on account of the absence of the sun: consequently there arises from within the earth a streaming movement like the ebb of the tides, in a sense contrary to the flow of the sea without; and this phenomenon generally develops about daybreak; it is at this time that the blasts ordinarily commence to blow. If therefore the force of them by chance turns quickly around, as Euripus (does), on account of the mighty tides of the sea, it produces an earthquake.

"Indeed it is about places of this kind that the mightiest of the earthquakes arise, where the sea is boisterous or the land is porous and cavernous. Wherefore they occur also about the Hellespont, and about Achaia, and Sicily, and about the analogous places of Eubœa; for the sea seems to pass through conduits under the earth. Hence also the warm springs around Aidepsus are produced by the same cause. And around the aforesaid places the earthquakes arise chiefly on account of the narrowness of the conduits; for the current of wind, which ordinarily blows from the land, finds itself driven back by the fullness of the sea which in such places becomes violent.

"The localities which have such caverns below thereby retaining much vapor, are most shaken by earthquakes, and in the spring and the end of autumn principally, and they rise both in the rainy and the dry seasons from the same cause; for these are the seasons in which there is most blowing of wind; in fact both summer and winter, the one by the frigidity and the other by the heat, produces calms; the one being exceedingly cold and the other exceedingly dry.

"Moreover in the dry seasons the air is very windy; for the dryness develops precisely when the dry exhalation is more considerable than the humidity; and in the rainy seasons the internal exhalation increases, and as it finds itself intercepted in very narrow places, and violently confined in a

less space because the cavities are full of water, the stream of wind begins to acquire the force for even the compression of its own bulk in this too limited space; and flowing out and striking against the passages the wind produces a violent earthquake; for it is necessary to bear in mind that, just as in our own body, the force of the breath held within produces a trembling and suffocation, so also in the earth the blast of vapor has an analogous effect; and that the shocks of earthquakes are partly of the nature of trembling and partly of suffocation, just as it often comes to pass after urination that a kind of vibration of the body is produced, a trembling with sudden drawing of the breath from without to the interior; thus arise also such phenomena with respect to the earth.

"In order to take proper account of all the influence which the blast of vapor exerts, it is necessary to observe not only what takes place in the air; for one can believe in the power of such things by their magnitude; but also what happens in the bodies of animals; convulsions and spasms are only motions of the breath, and they have such violence that often several persons uniting all their efforts are unable to keep the movements of the afflicted under control. Now it is necessary to bear in mind that the same thing happens also in the earth, since we naturally judge the great by reference to the small.

"Signs of these things, and according to our own observation, have occurred in many places; for the shaking of the earth arising in certain localities does not cease till the agitating wind has escaped freely into the region above the earth like the blast of a hurricane; it is not long ago since this actually happened at Heraclea in Pontus, and formerly at the island of Hiera, which is one of the islands called after Æolus; in this some earth swelled up, and with a loud noise rose in the form of a hill, and having finally broke forth, the mighty urging blast escaped and ejected sparks and ashes, which covered the region about the Lapari islands, spread over the whole land, and extended even to several cities in Italy: and at the present time where this eruption occurred is still evident; and now the development of fire in the earth must be held to have caused this, at the time of the first outbreak, the particles being reduced to the size of the finest dust of the air. Moreover, it is proved that blasts of vapor circulated beneath the earth, and that this occurred at these islands; for whenever the south wind starts to blow, there are first some premonitory signs of it: for places have it from which eruptions occur, because the sea is already agitated far and wide; and it again confines the swelling vapor within the earth, for the simple reason that the sea is spread over it.

"Accordingly it makes a noise without an earthquake, throughout the open spaces of these regions (imagined as deep conduits), either because the places are very vast, since above the earth they expend into immensity, or because the quantity of air expelled is very small.

"Moreover, the changes of the sun, which grows faint and dark without clouds, and the stillness and extreme cold, which sometimes precede the earthquakes occurring at daybreak are only additional signs of the aforesaid cause; for the sun must be obscured and darkened when the blast of vapor begins to sink within the earth, for dissolving and expelling the air,

and the winds must cease before dawn, and at daybreak, when the cold causes a stillness; for necessarily the stillness in most cases comes to pass, just as was also said before, because it is a reflex of the blast going within the earth, and happens especially before the greatest earthquakes; the blast of vapor is not much scattered, either that without or that within the earth, but borne along its course becomes at daybreak necessarily most violent.

"The cold comes to pass on account of the exhalation of the vapor circulating within, with all the heat naturally contained in it. If the winds do not seem to be warm it is because they move the air filled with cold vapor and considerable steam, just as in the case of the breath exhaled from the mouth; in fact this vapor is but slightly warm, as when we breathe; yet on account of the small amount of the air, the heat of it is not so evident; but further away the breath is cold from the same cause that the winds are.

"From the time that this force enters within the earth, the flowing away of the vapor combined with the moisture makes the cold, in places where this phenomenon is encountered. This is also the cause which ordinarily makes a sign before earthquakes; for whether by day, or a little after sunset, when the sky is clear, a faint cloud appears spreading and lengthening itself out, as a fine line perfectly straight, the blast of wind quieting down on account of the setting (of the sun). Whence similar phenomena come to pass also in the sea, about the shores; and especially whenever it is thrown into billowy waves, exceedingly violent and irregular, breakers at the beach are produced; but whenever a calm arises, because the breaking of the surface is very slight, the waves are small and regular.

"Accordingly that which the sea does around the land, the wind does about the dark clouds of vapor in the air. So that whenever the wind calms down, the cloud which remains is exactly a straight line and very tenuous, as if it were a mere wave of diffuse air.

"On account of these things therefore an earthquake is sometimes produced during the eclipses of the moon; for whenever the closing up of the earth between the sun and moon is near at hand, and the light is not yet indeed altogether gone, and the heat from the sun is still in the air, but already languishing, a calm arises by the wind suddenly whirling about and throwing itself in the earth, which produces the earthquake before eclipses; for the winds often arise before eclipses, winds at nightfall before eclipses at midnight, and winds at midnight before those at dawn. And this comes to pass on account of extinguishing the heat from the moon, whenever the event is already near; in which development the eclipse consists. That which holds the air and calms it having disappeared, it is agitated anew, and a blast of wind arises late in the evening previous to the eclipse.

"But whenever a powerful earthquake occurs it neither ceases immediately nor with a single disturbance; but sometimes it shakes for about forty days; upwards of one and even two years is indicated at certain places. The cause of the violence is the greatness and fullness of the blast of vapor, and the forms of the places from which it flows; that which it strikes against but does not easily penetrate, shakes most; and it necessarily agitates in the narrow places, just as in the case of obstructed water which is not able to pass through. Wherefore just as in the body the inflamed throbbings do

not cease of a sudden, nor rapidly, but by gradual giving away, along with the decrease of the symptom, so likewise the cause that produces the exhalation of vapor, and the first shock of the blast, do not at once set free the matter, from which are developed the kind of wind, which we call an earthquake. Until therefore the rest of these vapors has escaped the shaking of the earth necessarily continues. But it acts more and more feebly, till the time when the exhalation is too reduced to make a movement which remains sensible.

"And the blast of vapor also makes those sounds which arise beneath the earth, and those which precede earthquakes. And even without earthquakes there are places where these noises are developed under the earth; for just as the air when struck and rent produces all kinds of noises, so likewise also the ground itself produces noises when shaken; for there is no difference, since in the shock everything which agitates is itself shaken in its entirety. The roaring precedes the commotion, because the sound has parts as tenuous as the wind itself, and it penetrates as easily through all bodies.

"And whenever it is unable to move the earth on account of its very lightness, it is certain, since it passes through without difficulty, that it does not make it tremble, but according as it strikes against hard substances with cavities, and all manner of shapes, so they give off all kinds of sounds; consequently it sometimes seems, just as the marvel-mongers say, that the earth is made to roar.

"Occasionally as the result of earthquakes water gushes forth from the ground; but one is not able to say on this account that it was the water which caused the commotion; on the contrary it is always the blast of wind, whether from the surface, or confined below the earth, that produces the violence; and this is the moving power, just as one may say that the winds develop waves in the sea but the waves are not the cause of the winds; and thus then one may say that this earth itself is the cause of the phenomenon; for having been shaken it oscillates, just as water does, for the wave is a kind of oscillation; but the cause of the phenomenon is the same in both (the water and the earth); it experiences the agitation, yet does not produce it; but the blast of vapor is the real cause.

"Wherever along with an earthquake an inundation is produced the cause of it is the development of blasts of wind of a contrary nature. This happens whenever the blast of wind which shakes the earth is unable to repel completely the sea, which another blast of wind controls, nevertheless meeting it, opposing it, and confining it, gathering much force at the same point; for then necessarily the blast of wind confined in the earth by the sea cannot be resisted from breaking open a passage against the force of the opposite blast, and making a cataclysm.

"This is exactly what happened in the region of Achaia; for above the earth there was the south wind on one side, the north wind on the other. A calm having arisen, and the wind flowing within, there was produced at the same time an inundation and the accompanying earthquake; and the violence arose chiefly because the sea would not give passage to the wind imprisoned under the earth, but on the contrary obstructed it. Then having forced open other passages, the blast of vapor produced the earthquake, and the rising of the great sea wave caused the cataclysm.

"On the other hand earthquakes are produced, and often extend over but a small area; yet the winds are not local in character; on the contrary they arise whenever the exhalations, those over the area itself, and those of the neighbouring region, act in concert; just as we say the droughts are produced, and the rainy seasons in turn at any given place. And the earthquakes are produced likewise in the very same manner; but it is not so for the winds, for all these phenomena (the earthquakes, droughts and rains) have their origin in the earth, in such a way that they work together; the power of the sun, however, is not similar, but is rather exerted upon those exhalations high above the earth, so that whenever they experience the influence of the sun's annual circuit, according to the differences of the places on the earth, they all flow together.

"Whenever there is therefore considerable exhalation it shakes the earth, as in a trembling to and fro; it occurs more rarely, and only in certain places, as a pulsation, oscillating up and down; wherefore also shocks of this kind are of slight intensity; for it is not easy for a body of the elements to join together in this movement; since the secretion of vapor is many times larger at the surface than at great depths. Wherever such an earthquake arises, there is a hurling forth of a multitude of stones, just as in the case of sand winnowed by the wind. In this manner, when such an earthquake occurred, ejection of stones took place in Sicily, in the region called the Phlegræan fields, and in the Ligurian country.

"And in the islands of the deep sea earthquakes occur less often than in the islands near the continents. The immensity of the sea cools the exhalations, and it hinders them and resists them by the weight which it imposes upon them. Moreover even when the winds blow the sea always oscillates, and is not shaken powerfully by the agitating blasts.

"But on account of the enormous space it occupies it is not in it, but from it that the exhalations are produced, and those from the earth follow them: and the islands lying close to the mainland are only a part of the mainland itself; the space between, on account of its smallness, being of no importance; but those islands in the sea cannot be moved without disturbng the whole sea, which is spread around them. So much therefore may be said in regard to earthquakes, and their nature, and the cause through which they arise, and the other most important circumstances closely associated with them."

De Mundo,[1] Cap. IV.

(Scholars do not consider this work a genuine production of Aristotle, but no doubt it represents the Peripatetic School of Philosophy.)

"A blast of vapor erupting from the earth is carried upwards from the depths below or from the yawning fissure; whenever it is borne with muçh whirling movement there is a terrestrial thunderstorm; the blast of vapor ascends to the clouds, dense and moist, and outwardly scatters violently the

[1] περὶ κόσμου πρὸς 'Αλέξανδρον. This must not be confused with the treatise on the heavens, which is entitled περὶ οὐρανου.

collected mass of the cloud, and gives rise to a great noise and clashing, called thunder, just as in water (when heated) a blast of steam breaks forth violently. During the outbreak from the cloud the blast becomes fiery and brilliant, and is called lightning; it strikes before the thunder because it develops before it. . . .

"Now just as the earth includes within it a large amount of water, so likewise it contains also blasts of vapor, and streams of fire. And of these, those which are beneath the earth are obviously invisible; but many have vents, and eruptions, just as Lapari and Aetna and places in the islands of Æolus; which indeed often produce flows as in rivers and belch forth red hot streams of fire; some coming from beneath the earth, near springs of water, heat them, while others arise from springs of lukewarm character; the former being extremely hot, the latter agreeably tempered."

"And similarly many blasts of vapor break out from cavities everywhere in the earth; some of these communicate great enthusiasm to those who approach them, while others cause a languishing effect; and again others are made to sing oracles, as those in Delphi, and in Lebadia, and finally there are some which wholly destroy one another, just as those in Phrygia.

"And quite often also a blast of vapor conveniently tempered in the earth issues forth into its innermost passages, making strange sounds from familar places, and a large part of the blast flows out. Very often also a strong blast of vapor arises from without, and is absorbed in the cavities of the earth, shutting off the escape, and with force shaking it, seeking to break open its own orifice, and producing the phenomena which we are accustomed to call an earthquake.

"And of earthquakes there are some which shake sidewise, at acute angles (obliquely), called *epiclintae;* those shaking upward and downward, at right angles, *brastae,* those in which the ground collapses, making hollows, *chasmatiae,* those opening chasms and breaking the ground all to pieces, called *rhectae.* And of all these, there are some which permit the escape of a blast of vapor; others which throw up stones; others which eject earth, some which disclose sources not suspected before; and still others returning to equilibrium after a single shock, which they call *ostae;* those which rebound, the disturbed body oscillating to and fro, so as always to restore the equilibrium, such shaking is called *palmatiæ,* which produces a phenomenon like a trembling.

"There arises also earthquakes with subterranean thunder, shaking the earth with a roaring noise. Very often apart from an earthquake there arises a roaring of the earth, whenever the vapor is not strong enough to shake it, but nevertheless circulates within, endowed with a powerful rotatory motion.

"There are likewise blasts of vapor which enter the earth's interior, and are absorbed by the waters hidden within the earth. These phenomena are analogous to those which occur in the sea; for there are also chasms where the sea opens out and again when it withdraws, and there is an inundation of waves, and they have a recoil; and occasionally there is only a single pushing away of the sea (πρόωσις), just as is related indeed of Helike and of Boura.

y there is also produced an eruption of fire from the sea, and of springs, and a breaking forth of rivers, and an uprooting ..nole eddies and whirlpools, analogous to those due to blasts of e of these phenomena occur on the depths of the sea, others in nd the straits near the land.

ıy ebbs and flows of waves are said to run in always with the certain well determined epochs. To speak of the whole in a few we may therefore say that the elements mixing together among them- in the air, the earth and the sea, there is only considerable probability similar properties combining together, bringing to diverse creatures or life partially, but on the whole conserving the indestructible uni- ust as it is uncreated. . . .

"In reality terrible earthquakes have thrown in confusion many parts of the earth; the rains suddenly falling produce floods, and ominous outbreaks; inundations of waves, and recessions of the water makes sea where it was land and land where it was sea; the force of the winds and typhoons, are such as to overturn whole cities; volcanoes indeed and flames have broken out, which coming as of old from the heavens, just as they say since the time of Phaethon (driver of the sun's chariot), have burned up the parts towards the dawn; but on the other hand towards hesperus, they issue forth and radiate from the earth, just as the craters which have sent forth the flames of Ætna, and spreading over the ground are carried down as a torrent.

"It is in the terrible catastrophes arising from such an outpouring that the Diety has conspicuously honored the race of the pious who permit themselves to be surrounded by fiery streams of lava, when they take upon their shoulders their aged parents and save them; for when it nears them, the stream of fire, having developed as a river, divides, turning aside here, and again there, and spares the young persons along with their parents, without harming them. And in general, what the pilot is to the ship, the driver to the chariot, the leader to the choir, the law in the state, the general in the army, this the Diety is in the Cosmos."

§ 20. *The Theory of Strabo* (66 B. C.–24 A. D.).

The translation of Strabo's Geography included in Bohn's Library is acknowledged to be good; we shall therefore quote from it some extracts which exhibit Strabo's views. In the introduction to Strabo's "Geography" (Chap. III., § 3–4), this interesting passage occurs:

"Again, having discoursed on the advance of knowledge respecting the geography of the inhabited earth, between the time of Alexander and the period when he was writing, Eratosthenes goes into a description of the figure of the earth; not merely of the habitable earth, an account of which would have been very suitable, but of the whole earth, which should certainly have been given too, but not in this disorderly manner. He proceeds to tell us that the earth is spheroidal, not however perfectly so, inasmuch as it has certain irregularities, then enlarges on the successive changes of form, occasioned by water, fire, earthquakes, eruptions, and the like; all of which

is entirely out of place, for the spheroidal form of the whole earth is the result of the system of the universe, and the phenomenon which he mentions do not in the least change its general form; such little matters being entirely lost in the great mass of the earth. Still they cause various peculiarities in different parts of our globe, and result from a variety of causes.

"He points out as a most interesting subject for disquisition the fact of our finding, often quite inland, two or three thousand stadia from the sea, vast numbers of muscle, oyster, and scallop-shells, and salt-water lakes. He gives as an instance, that about the temple of Ammon, and along the road to it for the space of 3,000 stadia, there are yet found a vast amount of oyster shells, many salt-beds, and salt springs bubbling up, besides which are pointed out numerous fragments of wreck which they say have been cast up through some opening, and dolphins placed on pedestals with the inscriptions, Of the delegates from Cyrene. Herein he agrees with the opinion of Strato the natural philosopher, and Xanthus of Lydia. Xanthus mentioned that in the reign of Ataxerxes there was so great a drought, that every river, lake, and well was dried up: and that in many places he had seen a long way from the sea fossil shells, some like cockles, others resembling scallop shells, also salt lakes in Armenia, Matiana and Lower Phrygia, which induced him to believe that the sea had formerly been where the land now was. Strato, who went more deeply into the cause of these phenomena, was of opinion that formerly there was no exit to the Euxine as now at Byzantium, but that the rivers running into it had forced a way through, and thus let the waters escape into the Propontis, and thence to the Hellespont. And that a like change had occurred in the Mediterranean. For the sea being overflowed by the rivers, had opened for itself a passage by the Pillars of Hercules, and thus, much that was formerly covered by water, had been left dry. He gives as the cause of this, that anciently the levels of the Mediterranean and Atlantic were not the same, and states that a bank of earth, the remains of the ancient separation of the two seas, is still stretched under water from Europe to Africa. He adds, that the Euxine is the most shallow, and the seas of Crete, Sicily and Sardinia much deeper, which is occasioned by the number of large rivers flowing into the Euxine both from the north and east, and so filling it up with mud, whilst the others preserve their depth. This is the cause of the remarkable sweetness of the Euxine Sea, and of the currents which regularly set towards the deepest part. He gives it as his opinion, that should the rivers continue to flow in the same direction, the Euxine will in time be filled up (by the deposits), since already the left side of the sea is little else than shallows, as also Salmydessus, and the shoals at the mouth of the Ister, and the desert of Scythia, which sailors call the Breasts. Probably too the temple of Ammon was originally close to the sea, though now, by the continual deposit of the waters, it is quite inland: and he conjectures that it was owing to its being so near the sea that it became so celebrated and illustrious, and that it never would have enjoyed the credit it now possesses had it always been equally remote from the sea. Egypt too (he says) was formerly covered by sea as far as the marshes near Pelusium, Mount Casius, and the Lake Sirbonis. Even at the present time, when salt is being dug in Egypt, the beds are found under layers of sand and mingled

with fossil shells, as if this whole district had formerly been under water, and as if the whole region about Casium and Gerrha had been shallows reaching to the Arabian Gulf. The sea afterwards receding left the land uncovered, and the Lake Sirbonis remained, which having afterwards forced itself a passage, became a marsh. In like manner the borders of the Lake Mœris resemble a sea-beach rather than the banks of a river. Every one will admit that formerly at various periods a great portion of the mainland has been covered and again left bare by the sea. Likewise that the land now covered by the sea is not all on the same level, any more than that whereon we dwell, which is now uncovered and has experienced so many changes, as Eratosthenes has observed. Consequently in the reasoning of Xanthus there does not appear to be anything out of place.

"In regard to Strato, however, we must remark that, leaving out of the question the many arguments he has properly stated, some of those which he has brought forward are quite inadmissible. For first he is inaccurate in stating that the beds of the interior and the exterior seas have not the same level, and that the depth of the two seas is different; whereas the cause why the sea is at one time raised, at another depressed, that it inundates certain places and again retreats, is not that the beds have different levels, some higher and some lower, but simply this, that the same beds are at one time raised, at another depressed, causing the sea to rise or subside with them; for having risen they cause an inundation, and when they subside the waters return to their former places. For if it is so, an inundation will of course accompany every sudden increase of the waters of the sea, (as in the spring tides) or the periodical swelling of rivers, in the one instance the waters being brought together from distant parts of the ocean, in the other, their volume being increased. But the rising of the rivers are not violent and sudden, nor do the tides continue any length of time, nor occur irregularly; nor yet along the coast of our sea do they cause inundations nor anywhere else. Consequently we must seek for an explanation of the cause either in the stratum composing the bed of the sea, or in that which is overflowed; we prefer to look for it in the former, since by reason of its humidity it is more liable to shiftings and sudden changes of position, and we shall find that in these matters the wind is the great agent after all. But, I repeat it, the immediate cause of these phenomena, is not in the fact of one part of the bed of the ocean being higher or lower than another, but in the upheaving or depression of the strata on which the waters rest. Strato's hypothesis evidently originated in the belief that that which occurs in rivers is also the case in regard to the sea; viz. that there is a flow of water from the higher places."

Again in Chap. III., section 10:

"Some, however, may be disinclined to admit this explanation, and would rather have proof from things more manifest to the senses, and which seem to meet us at every turn. Now deluges, earthquakes, eruptions of wind, and risings in the bed of the sea, these things cause the rising of the ocean, as sinking of the bottom causes it to become lower. It is not the case that small volcanic or other islands can be raised up from the sea, and not large

ones, nor that all islands can, but not continents, since extensive sinkings of the land no less than small ones have been known; witness the yawning of those chasms which have engulfed whole districts no less than their cities, as is said to have happened to Bura, Bizone, and many other towns at the time of earthquakes: and there is no more reason why one should rather think Sicily to have been disjoined from the mainland of Italy than cast up from the bottom of the sea by the fires of Aetna, as the Lipari and Pithecussan Isles have been."

In Chap. III., sections 16 and 17, we read:

"In order to lessen surprise at such changes as we have mentioned as causes of the inundations and other similar phenomena which are supposed to have produced Sicily, the islands of Aeolus and the Pithecussae, it may be as well to compare with these others of a similar nature, which either now are, or else have been observed in other localities. A large array of such facts placed at once before the eye would serve to allay our astonishment; while that which is uncommon startles our perception, and manifests our general ignorance of the occurrence which takes place in nature and physical existence. For instance, supposing any one should narrate the circumstances concerning Thera and the Therasian Islands, situated in the strait between Crete and the Cyrenaic, Thera being itself the metropolis of Cyrene; or those (in connexion with) Egypt, and many parts of Greece. For midway between Thera and Therasia flames rushed forth from the sea for the space of four days; causing the whole of it to boil and be all on fire; and after a little an island twelve stadia in circumference, composed of the burning mass, was thrown up, as if raised by machinery. After the cessation of this phenomenon, the Rhodians, then masters of the sea, were the first who dared to sail to the place, and they built there on the island a temple to the Asphalian Neptune. Posidonius remarks, that during an earthquake which occurred in Phoenicia, a city situated above Sidon was swallowed up, and that nearly two thirds of Sidon also fell, but not suddenly, and therefore with no great loss of life. That the same occurred, though in a lighter form, throughout nearly the whole of Syria, and was felt even in some of the Cyclades and the Island of Euboea, so that the fountains of Arethusa, a spring in Chalcis, were completely obstructed, and after some time forced for themselves another opening, and the whole island ceased not to experience shocks until a chasm was rent open in the earth in the plain of Lelanto, from which poured a river of burning mud.

"17. Many writers have recorded similar occurrences, but it will suffice to narrate those which have been collected by Demetrius of Skepsis.

"Apropos of that passage of Homer:

"'And now they reach'd the running rivulets clear,
Where from Scamandar's dizzy flood arise
Two fountains, tepid one, from which a smoke
Issues voluminous as from a fire.
The other, even in summer heats, like hail
For cold, or snow, or crystal stream frost-bound:'"

"this writer tells us we must not be surprised, that although the cold spring still remains, the hot cannot be discovered; and says we must reckon the failing of the hot spring as the cause. He goes on to relate certain catastrophes recorded by Democles, how formerly in the reign of Tantalus there were great earthquakes in Lydia and Ionia as far as the Troad, which swallowed up whole villages and overturned Mount Sipylus; marshes then became lakes, and the city of Troy was covered by the waters. Pharos, near Egypt, which anciently was an island, may now be called a peninsula, and the same may be said of Tyre and Clazomenæ."

In Chap. III., section 18:

"Of Bura and Helice, one has been swallowed by an earthquake, the other covered by the waves. Near to Methone, which is on the Hermionic Gulf, a mountain seven stadia in height was cast up during a fiery eruption; during the day it could not be approached on account of the heat and sulphureous smell; at night it emitted an agreeable odour, appeared brilliant at a distance, and was so hot that the sea boiled around it to a distance of five stadia, and appeared in a state of agitation for twenty stadia, the heap being formed of fragments of rock as large as towers."

In Chap. III., sections 19–21, we find this account:

"Duris informs us that the Rhagæ in Media gained that appellation from chasms made in the ground near the Gates of the Caspian by earthquakes, in which many cities and villages were destroyed, and the rivers underwent various changes. Ion, in his satirical composition of Omphale, has said of Eubœa,

"'The light wave of the Euripus has divided the land of Eubœa from Bœotia, separating the projecting land by a strait.'

"20. Demetrius of Callatis, speaking of the earthquakes which formerly occurred throughout the whole of Greece, states that a great portion of the Lichadian Islands and of Kenæum were submerged; that the hot springs of Ædepsus and Thermopylæ were suppressed for three days, and that when they commenced to run again those of Ædepsus gushed from new fountains. That at Oreus on the sea coast the wall and nearly seven hundred houses fell at once. That the greater part of Echinus, Phalara, and Heraclæa of Trachis were thrown down, Phalara being overturned from its very foundations. That almost the same misfortune occurred to the Lamians and inhabitants of Larissa; that Scarpheia was overthrown from its foundations, not less than one thousand seven hundred persons being swallowed up, and at Thronium more than half that number. That a torrent of water gushed forth taking three directions, one to Scarphe and Thronium, another to Thermopylæ, and a third to the plains of Daphnus in Phocis. That the springs of (many) rivers were for several days dried up; that the course of the Sperchius was changed, thus rendering navigable what formerly was highways; that the Boagrius flowed through another channel; that many parts of Alope, Cynus and Opus were injured, and the castle of Œum, which commands the latter city, entirely overturned. That part of the wall of Elateia was thrown down; and that at Alponus, during the celebration of the

games in honour of Ceres, twenty-five maidens, who had mounted a tower to enjoy the show exhibited in the port, were precipitated into the sea by the falling of the tower. They also record that a large fissure was made (by the water) through the midst of the island of Atalanta, opposite Eubœa, sufficient for ships to sail in; that the course of the channel was in places as broad as twenty stadia between the plains; and that a trireme being raised (thereby) out of the docks, was carried over the walls."

Strabo's description of Vesuvius is of interest:

"Above these places is Mount Vesuvius, which is covered with very beautiful fields, excepting its summit, a great part of which is level, but wholly sterile. It appears ash-coloured to the eye, cavernous hollows appear formed of blackened stones, looking as if they had been subjected to the action of fire. From this we may infer that the place was formerly in a burning state with live craters, which however became extinguished on the failing of the fuel. Perhaps this (volcano) may have been the cause of the fertility of the surrounding country, the same as occurs in Catana, where they say that that portion which has been covered with ashes thrown up by the fires of Ætna is most excellent for the vine." (Lib. V., Cap. 4, § 8; p. 367 in vol. I of Bohn's Transl.).

Again in Lib. V., Cap. 4, § 9, he continues:

"In front of Misenum lies the island of Prochyta, which has been rent from the Pithecussæ. Pithecussæ was peopled by a colony of Eretrians and Chalcidians, which was very prosperous on account of the fertility of the soil and the productive gold-mines; however, they abandoned the island on account of civil dissensions, and were ultimately driven out by earthquakes, and eruptions of fire, sea, and hot waters. It was on account of these eruptions, to which the island is subject, that the colonists sent by Hiero, the king of Syracuse, abandoned the island, together with the town which they had built, when it was taken possession of by the Neapolitans. This explains the myth concerning Typhon, who, they say, lies beneath the island, and when he turns himself, causes flames and water to rush forth, and sometimes even small islands to rise in the sea, containing springs of hot water. Pindar throws more credibility into the myth, by making it conformable to the actual phenomena, for the whole strait from Cumaea to Sicily is subigneous, and below the sea has certain galleries which form a communication between (the volcanoes of the island) and those of the main-land. He shows that Aetna is on this account of the nature described by all, and also the Lipari Islands, with the regions around Dicæarchia, Neapolis, Baiae, and the Pithecussæ. And mindful hereof, (Pindar) says that Typhon lies under the whole of the space.

"'Now indeed the sea-girt shores beyond Cumæ, and Sicily, press on his shaggy breast.'

"Timæus, who remarks that many paradoxical accounts were related by the ancients concerning the Pithecussæ, states, nevertheless, that a little before his time, Mount Epomeus, in the middle of the island, being shaken by an earthquake, vomited forth fire; and that the land between it and the coast was driven out into the sea. The powdered soil, after being whirled

high, was poured down again upon the island in a whirlwind. That the sea retired from it to a distance of three stadia, but after remaining so for a short time it returned, and inundated the island, thus extinguishing the fire. And the inhabitants of the continent fled at the noise, from the sea-coast, into the interior of Campania."

The following passage about the town of the Rhegini gives Strabo's views of volcanoes as safety valves (Lib. VI., Cap. I, § 6, pp. 386–387):

"It was called Rhegium either, as Aeschylus says, because of the convulsions which had taken place in this region; for Sicily was broken from the continent by earthquakes,

"'Whence it is called Rhegium.'

Others, as well as he, have affirmed the same thing, and adduce as an evidence that which is observed about Ætna, and the appearances seen in other parts of Sicily, the Lipari and neighbouring islands, and even in the Pithecussæ, with the whole coast beyond them, which prove that it was not unlikely that this convulsion had taken place. But now these mouths being opened, through which fire is drawn up, and the ardent masses and water poured out, they say that the land in the neighbourhood of the Strait of Sicily rarely suffers from the effects of earthquakes; but formerly all the passages to the surface being blocked up, the fire which was smouldering beneath the earth, together with the vapour, occasioned terrible earthquakes, and the regions, being disturbed by the force of the pent up winds, sometimes gave way, and being rent received the sea, which flowed in from either side; and thus were formed both this strait and the sea which surrounds the other islands in the neighbourhood. For Prochyta and the Pithecussæ, as well as Capreæ, Leucosia, the Sirenes, and the Œnotrides, are but so many detached fragments from the continent, but other islands have risen from the bottom of the sea, a circumstance which frequently occurs in many places; for it is more reasonable to think that the islands in the midst of the ...e been raised up from the bottom, and that those which lie off head- ...re separated merely by a strait were broken off from them."

...bing Mount Aetna he says (Lib. VI., Cap. 2, § 8–9; ...:

...entoripa is the town we have a little before mentioned, Ætna, ... a place for travelers about to ascend Mount Ætna, to halt ...nselves for the expedition. For here commences the region ...ated the summit of the mountain. The districts above are ...red with ashes, which are surmounted by the snows in winter; ...owever is filled with woods and plantations of all kinds. It ...e summits of the mountain take many changes by the ravages ... which sometimes is brought into one crater, and at another is ... one time again it heaves forth streams of lava, and at another ...d thick smoke: at other times again ejecting red-hot masses of ... In such violent commotions as these the subterranean passages

must necessarily undergo a corresponding change, and at times the orifices on the surface around be considerably increased. Some who have very recently ascended the mountain, reported to us, that they found at the top an even plain of about 20 stadia in circumference, enclosed by an overhanging ridge of ashes about the height of a wall, so that those who are desirous of proceeding further are obliged to leap down into the plain. They noticed in the midst of it a mound; it was ash-coloured, as was likewise the plain in appearance. Above the mound a column of cloud reared itself in a perpendicular line to the height of 200 stadia, and remained motionless (there being no air stirring at the time); it resembled smoke. Two of the party resolutely attempted to proceed further across this plain, but, finding the sand very hot and sinking very deep in it, they turned back, without however being able to make any more particular observations, as to what we have described, than those who beheld from a greater distance. They were, however, of opinion, from the observations they were able to make, that much exaggeration pervades the accounts we have of the volcano, and especially the tale about Empedocles, that he leaped into the crater, and left as a vestige of his folly one of the brazen sandals which he wore, it being found outside at a short distance from the lip of the crater, with the appearance of having been cast up by the violence of the flame; for neither is the place approachable nor even visible, nor yet was it likely that anything could be cast in thither, on account of the contrary currents of vapours and other matters cast up from the lower parts of the mountain, and also on account of the overpowering excess of heat, which would most likely meet any one before approaching the mouth of the crater; and if eventually any thing should be cast down, it would be totally decomposed before it were cast up again, what manner of form soever it might have had at first. And again, although it is not unreasonable to suppose that the force of the vapour and fire is occasionally slackened for want of a continual supply of fuel, still we are not to conclude that it is ever possible for a man to approach it in the presence of so great an opposing power. Ætna more especially commands the shore along the Strait and Catana, but it also overlooks the sea that washes Tyrrhenia and the Lipari Islands. By night a glowing light appears on its summit, but in the day-time it is enveloped with smoke and thick darkness.

"The Nebrodes mountains take their rise opposite to Ætna; they are not so lofty as Ætna, but extend over a much greater surface. The whole island is hollow under ground, and full of rivers and fire like the bed of the Tyrrhenian Sea, as far as Cumæa, as we before described. For there are hot springs in many places in the island, some of which are saline, as those named Selinuntia and the springs at Himera, while those at Ægesta are fresh."

Again (Lib. VI., cap. 2, § 10; pp. 417–418) Strabo says:

"Phænomena, similar to these, and such as take place throughout Sicily, are witnessed in the Lipari Islands, and especially in Lipari itself. These islands are seven in number, the chief of which is Lipari, a colony of the Cnidians. It was nearest to Sicily after Thermessa. It was originally named

Meligunis. It was possessed of a fleet, and for a considerable time repelled the incursions of the Tyrrheni. The islands now called Liparæan were subject to it, some call them the islands of Æolus. The citizens were so successful as to make frequent offerings of the spoils taken in war to the temple of Apollo at Delphi. It possesses a fertile soil, and mines of alum easy to be wrought, hot springs, and craters. (Thermessa) is, as it were, situated between this and Sicily; it is now designated as Hiera, or sacred to Vulcan; it is entirely rocky, and desert, and volcanic. In it are three craters, and the flames which issue from the largest are accompanied with burning masses of lava, which have already obstructed a considerable portion of the strait (between Thermessa and the island Lipari); repeated observations have led to the belief that the flames of the volcanoes, both in this island and at Mont Ætna, are stimulated by the winds as they rise; and when the winds are lulled, the flames also subside; nor is this without reason, for if the winds are both originally produced and kept up by the vapours arising from the sea, those who witness these phenomena will not be surprised, if the fire should be excited in some such way, by the like aliment and circumstances. Polybius tells us that one of the three craters of the island has partly fallen down, while the larger of the two that remain has a lip, the circumference of which is five stadia, and the diameter nearly fifty feet, and its elevation about a stadium from the level of the sea, whch may be seen at the base in calm weather; but if we are to credit this, we may as well attend to what has been reported concerning Empedocles. (Polybius) also says, that when the south wind is to blow, a thick cloud lies stretched round the island, so that one cannot see even as far as Sicily in the distance; but when there is to be a north wind, the clear flames ascend to a great height above the said crater, and great rumblings are heard; while for the west wind effects are produced about half way between these two. The other craters are similarly affected, but their exhalations are not so violent. Indeed, it is possible to foretell what wind will blow three days beforehand, from the degree of intensity of the rumbling, and also from the part whence the exhalations, flames, and smoky blazes issue."

Strabo describes the Aeloian Islands, and includes this account of one of them (Lib. VI., cap. 2, § 11; pp. 420–421):

"The seventh (island) is called Euonymus; it is the fartherest in the sea and barren. It is called Euonymus because it lies the most to the left when you sail from the island of Lipari to Sicily, and many times flames of fire have been seen to rise to the surface, and play upon the sea round the islands: these flames rush with violence from the cavities at the bottom of the sea, and force for themselves a passage to the open air. Posodinius says, that at a time so recent as to be almost within his recollection, about the summer solstice and at break of day, between Hiera and Euonymus, the sea was observed to be suddenly raised aloft, and to abide sometime raised in a compact mass and then to subside. Some ventured to approach that part in their ships; they observed the dead fish driven by the current, and being distressed by the heat and foul smell, were compelled to turn back. One of the boats which approached the nearest lost some of her crew,

and was scarcely able to reach Lipari with the rest, and they had fits like an epileptic person, at one time fainting and giddy, and at another returning to their senses; and many days afterwards a mud or clay was observed rising in the sea, and in many parts the flames issued, and smoke and smoky blazes; afterwards it congealed and became a rock like mill-stones. Titus Flaminus, who then commanded in Sicily, despatched to the senate (of Rome) a full account of the phenomenon; the senate sent and offered sacrifieces to the infernal and marine divinities both in the little island (which had thus been formed) and the Lipari Islands."

Strabo mentions (Book viii., Chap. vi., § 19, Vol. II., p. 59) the cities enumerated in Homer's Catalogue of Ships (Illiad, ii., 569) including "spacious Helike" (Ἑλίκην εὐρεῖαν). In Book viii., Chap. vii., § 2; pp. 69–70, he recounts the development of Achaian power, and say they began in the time of Pyrrhus with four cities:

"They then had an accession of the twelve cities, with the exception of Olenus and Helice; the former refused to join the league; the other was swallowed up by the waves.

"For the sea was raised to a great height by an earthquake, and overwhelmed both Helice and the temple of the Heliconian Neptune, whom the Ionians still hold in great veneration, and offer sacrifices to his honour. They celebrate at that spot the Panionian festival. According to the conjecture of some persons, Homer refers to these sacrifices in these lines,

"'But he breathed out his soul, and bellowed, as a bull
Bellows when he is dragged round the altar of the Heliconian king.'

"It is conjectured that the age of the poet is later than the migration of the Ionian colony, because he mentions the Panionian sacrifices, which the Ionians perform in honour of the Heliconian Neptune in the territory of Priene; for the Prienians themselves are said to have come from Helice; a young man also of Priene is appointed to preside as king at these sacrifices, and to superintend the celebration of the sacred rites. A still stronger proof is adduced from what is said by the poet respecting the bull, for the Ionians suppose, that sacrifice is performed with favorable omen, when the bull bellows at the instant that he is wounded at the altar.

"Others deny this, and transfer to Helice the proofs alleged of the bull and the sacrifice, asserting that these things were done there by established custom, and that the poet drew his comparison from the festival celebrated there. Helice was overwhelmed by the waves two years before the battle of Leuctra. Eratosthenes says, that he himself saw the place, and the ferrymen told him that there formerly stood in the strait a brazen statue of Neptune, holding in his hand a hippocampus, an animal which is dangerous to fishermen.

"According to Heracleides, the inundation took place in his time, and during the night. The city was at the distance of twelve stadia from the sea, which overwhelmed the whole intermediate country as well as the city. Two thousand men were sent by the Achæans to collect the dead bodies, but in vain. The territory was divided among the bordering people. This

calan happened in consequence of the anger of Neptune, for the Ionians, w were driven from Helice, sent particularly to request the people of H give them the image of Neptune, or if they were unwilling to gi to furnish them with the model of the temple. On their refusal, the Ionians sent to the Achæan body, who decreed, that they should comply with the request, but they would not obey even this injunction. The disaster occurred in the following winter, and after this the Achæans gave the Ionians the model of the temple."

§ 21. *The Theory of Pliny (23–79 A.D.).*

The following extracts are taken from Bohn's excellent translation of the "Natural History." They exhibit the views of Pliny, who follows closely the theory of Aristotle.

In Book II., of the Natural History, will be found Pliny's account of earthquakes, which runs thus:

"CHAP. 81 (79)—OF EARTHQUAKES.

"According to the doctrine of the Babylonians,[1] earthquakes and clefts of the earth, and occurrences of this kind, are supposed to be produced by the influence of the stars, especially of the three to which they ascribe thunder (Saturn, Jupiter and Mars); and to be caused by the stars moving with the sun, or being in conjunction with it, and, more particularly, when they are in the quartile aspect. If we are to credit the report, a most admirable and immortal spirit, as it were of a divine nature, should be ascribed to Anaximander the Milesian, who, they say, warned the Lacedæmonians to beware of their city and their houses. For he predicted that an earthquake was at hand, when both the whole of their city was destroyed and a large portion of Mount Taygetus, which projected in the form of a ship, was broken off, and added farther ruin to the previous destruction. Another prediction is ascribed to Pherecydes, the master of Pythagoras, and this was divine; by a draught of water from a well, he foresaw and predicted that there would be an earthquake in that place. And if these things be true, how nearly do these individuals approach to the Diety, even during their lifetime! But I leave every one to judge of these matters as he pleases. I certainly conceive the winds to be the cause of earthquakes; for the earth never trembles except when the sea is quite calm, and when the heavens are so tranquil that the birds cannot maintain their flight, all the air which should support them being withdrawn; nor does it ever happen until after great winds, the gust being pent up, as it were, in the fissures and concealed hollows. For the trembling of the earth resembles thunder in the clouds; nor does the yawning of the earth differ from the bursting of the lightning; the enclosed air struggling and striving to escape.

"CHAP. 82 (80)—OF CLEFTS OF THE EARTH.

"The earth is shaken in various ways, and wonderful effects are produced; in one place the walls of cities being thrown down, and in others swallowed up by a deep cleft; sometimes great masses of earth are heaped

[1] Pliny here refers to the Astrologers, who were said to have come originally from Babylon.

up, and rivers forced out, sometimes even flame and hot springs, and at others the course of rivers is turned. A terrible noise precedes and accompanies the shock; sometimes a murmuring, like the lowing of cattle, or like human voices, or the clashing of arms. This depends on the substance which receives the sound, and the shape of the caverns or crevices through which it issues; it being more shrill from a narrow opening, more hoarse from one that is curved, producing a loud reverberation from hard bodies, a sound like a boiling fluid from moist substances, fluctuating in stagnant water, and roaring when forced against solid bodies. There is, therefore, often the sound without any motion. Nor is it a simple motion, but one that is tremulous and vibratory. The cleft sometimes remains, displaying what it has swallowed up; sometimes concealing it, the mouth being closed and the soil being brought over it, so that no vestige is left; the city being, as it were, devoured, and the tract of country engulfed. Maritime districts are more especially subject to shocks. Nor are mountainous tracts exempt from them; I have found, by my inquiries, that the Alps and the Apennines are frequently shaken. The shocks happen more frequently in the autumn and in the spring, as is the case also with thunder. There are seldom shocks in Gaul and in Egypt; in the latter it depends on the prevalence of summer, in the former of winter. They also happen more frequently in the night than in the day. The greatest shocks are in the morning and the evening; but they often take place at daybreak, and sometimes at noon. They also take place during the eclipses of the sun and of the moon, because at that time storms are lulled. They are most frequent when great heat succeeds to showers, or showers succeed to great heat.

"Chap. 83 (81)—Signs of an Approaching Earthquake.

"There is no doubt that earthquakes are felt by persons on shipboard, as they are struck by a sudden motion of the waves, without these being raised by any gust of wind. And things that are in the vessels shake as they do in houses, and give notice by their creaking; also the birds, when they settle upon the vessels, are not without their alarms. There is also a sign in the heavens; for, when a shock is near at hand, either in the daytime or a little after sunset, a cloud is stretched out in the clear sky, like a long thin line. The water in wells is also more turbid than usual, and it emits a disagreeable odour.

"Chap. 84 (82)—Preservatives against Future Earthquakes.

"These same places, however, afford protection, and this is also the case where there is a number of caverns, for they give vent to the confined vapour, a circumstance which has been remarked in certain towns, which have been less shaken where they have been excavated by many sewers. And, in the same town, those parts that are excavated are safer than the other parts, as is understood to be the case at Naples in Italy, the part of which is solid being more liable to injury. Arched buildings are also the most safe, also the angles of walls, the shocks counteracting each other; walls made of brick also suffer less from the shocks. There is also a great difference in the nature of the motions, where various motions are experienced.

It is safest when it vibrates and causes a creaking in the building, and when it swells and rises upwards, and settles with an alternate motion. It is also harmless when the buildings coming together butt against each other in opposite directions, for the motions counteract each other. A movement like the rolling of waves is dangerous, or when the motion is impelled in one direction. The tremors cease when the vapour bursts out; but if they do not soon cease, they continue for forty days; generally, indeed, for a longer time: some have lasted even for one or two years.

"CHAP. 85 (83)—PRODIGIES OF THE EARTH WHICH HAVE OCCURRED ONCE ONLY.

"A great prodigy of the earth, which never happened more than once, I have mentioned in the books of the Etruscan ceremonies, as having taken place in the district of Mutina, during the consulship of Lucius Martius and Sextus Julius. Two mountains rushed together, falling upon each other with a very loud crash, and then receding; while in the daytime flame and smoke issued from them; a great crowd of Roman knights, and families of people, and travellers on the Æmilian way, being spectators of it. All the farm-houses were thrown down by the shock, and a great number of animals that were in them were killed; it was in the year before the Social war; and I am in doubt whether this event or the civil commotions were more fatal to the territory of Italy. The prodigy which happened in our own age was no less wonderful; in the last year of the emperor Nero, as I have related in my history of his times, when certain fields and olive grounds in the district of Marrucinum, belonging to Vectius Marcellus, a Roman knight, the steward of Nero, changed places with each other, although the public highway was interposed.

"CHAP. 86 (84)—WONDERFUL CIRCUMSTANCES ATTENDING EARTHQUAKES.

"Inundations of the sea take place at the same time with earthquakes; the water being impregnated with the same spirit, and received into the bosom of the earth which subsides. The greatest earthquake which has occurred in our memory was in the reign of Tiberius, by which twelve cities of Asia were laid prostrate in one night. They occurred the most frequently during the Punic war, when we had accounts brought to Rome of fifty-seven earthquakes in the space of a single year. It was during this year that the Carthagenians and the Romans, who were fighting at the lake Thrasimenus, were neither of them sensible of a very great shock during the battle. Nor is it an evil merely consisting in the danger which is produced by the motion; it is an equal or a greater evil when it is considered as a prodigy. The city of Rome never experienced a shock, which was not the forerunner of some great calamity.

"CHAP. 87 (85)—IN WHAT PLACE THE SEA HAS RECEDED.

"The same cause produces an increase of the land; the vapour, when it cannot burst out forcibly lifting up the surface. For the land is not merely produced by what is brought down the rivers, as the islands called Echinades are formed by the river Achelous, and the greater part of Egypt by the Nile, where, according to Homer, it was a day and a night's journey from

the mainland to the island of Pharos; but in some cases, by the receding of the sea, as, according to the same author, was the case with the Circæan isles. The same thing also happened in the harbour of Ambracia, for a space of 10,000 paces, and was also said to have taken place for 5000 at the Piræus of Athens, and likewise at Ephesus, where formerly the sea washed the walls of the temple of Diana. Indeed, if we may believe Herodotus, the sea came beyond Memphis, as far as the mountains of Æthiopia, and also from the plains of Arabia. The sea also surrounded Ilium and the whole of Teuthrania, and covered the plain through which the Mæander flows.

CHAP. 88 (86)—THE MODE IN WHICH ISLANDS RISE UP.

"Land is sometimes formed in a different manner, rising suddenly out of the sea, as if nature was compensating the earth for its losses, restoring in one place what she had swallowed up in another.

"CHAP. 89 (87)—WHAT ISLANDS HAVE BEEN FORMED, AND AT WHAT PERIODS.

"Delos and Rhodes, islands which have now been long famous, are recorded to have risen up in this way. More lately there have been some smaller islands formed; Anapha, which is beyond Melos; Nea, between Lemnos and the Hellespont; Halone, between Lebedos and Teos; Thera and Therasia, among the Cyclades, in the fourth year of the 135th Olympiad. And among the same islands, 130 years afterwards, Hiera, also called Automate, made its appearance; also Thia, at the distance of two stadia from the former, 110 years afterwards, in our own times, when M. Junius Silanus and L. Balbus were consuls, on the 8th of the ides of July.

"88. Opposite to us, and near to Italy, among the Æolian isles, an island emerged from the sea; and likewise one near Crete, 2,500 paces in extent, and with warm springs in it; another made its appearance in the third year of the 163rd Olympiad, in the Tuscan gulf, burning with a violent explosion. There is a tradition too that a great number of fishes were floating about the spot, and that those who employed them for food immediately expired. It is said that the Pithecusan isles rose up, in the same way, in the bay of Campania, and that shortly afterwards, the mountain Epopos, from which flame had suddenly burst forth, was reduced to the level of the neighbouring plain. In the same island, it is said, that a town was sunk in the sea; that in consequence of another shock, a lake burst out, and that, by a third, Prochytas was formed into an island, the neighbouring mountains being rolled away from it.

"CHAP. 90—LANDS WHICH HAVE BEEN SEPARATED BY THE SEA.

"In the ordinary course of things islands are also formed by this means. The sea has torn Sicily from Italy, Cyprus from Syria, Eubœa from Bœotia. Atalante and Macris from Eubœa, Besbycus from Bithynia, and Leucosia from the promontory of the Sirens.

"CHAP. 91 (89)—ISLANDS WHICH HAVE BEEN UNITED TO THE MAINLAND.

"Again, islands are taken from the sea and added to the mainland; Antissa to Lesbos, Zephyrium to Halicarnassus, Æthusa to Myndus, Dro-

miscus and Perne to Miletus, Narthecusa to the promontory of Parthenium. Hybanda, which was formerly an island of Ionia, is now 200 stadia distant from the sea. Syries is now become a part of Ephesus, and, in the same neighborhood, Derasidas and Sophonia form part of Magnesia; while Epidaurus and Oricum are no longer islands.

"Chap. 92 (90)—Lands which have been Totally Changed into Seas.

"The sea has totally carried off certain lands, and first of all, if we are to believe Plato, for an immense space where the Atlantic ocean is now extended. More lately we see what has been produced by our inland sea; Acarnania has been overwhelmed by the Ambracian gulf, Achaia by the Corinthian, Europe and Asia by the Propontis and Pontus. And besides these, the sea has rent asunder Leucas, Antirrhium, the Hellespont, and the two Bosphori.

"Chap. 93 (91)—Lands which have been Swallowed up.

"And not to speak of bays and gulfs, the earth feeds on itself; it has devoured the very high mountain of Cybotus, with the town of Curites; also Sipylus in Magnesia, and formerly, in the same place, a very celebrated city, which was called Tantalis; also the land belonging to the cities Galanis and Gamales in Phœnicia, together with the cities themselves; also Phegium, the most lofty ridge in Æthiopia. Nor are the shores of the sea more to be depended upon.

"Chap. 94 (92)—Cities which have been Absorbed by the Sea.

"The sea near the Palus Mæotis has carried away Pyrrha and Antissa, also Elice and Bura in the gulf of Corinth, traces of which places are visible in the ocean. From the island Cea it has seized on 30,000 paces, which were suddenly torn off, with many persons on them. In Sicily also the half of the city of Tyndaris, and all the part of Italy which is wanting; in like manner it carried off Eleusina in Bœotia.

Again:

"Chap. 110 (106)—Places which are Always Burning.

"Among the wonders of mountains there is Ætna, which always burns in the night, and for so long a period has always had materials for combustion, being in the winter buried in snow, and having the ashes which it has ejected covered with frost. Nor is it in this mountain alone that nature rages, threatening to consume the earth; in Phaselis, the mountain Chimæra burns, and [illegible] with a continual flame, day and night. Ctesias of Cnidos inform[illegible] fire is kindled by water, while it is extinguished by [illegible] In the same country of Lycia, the mountains of Hephæs-[illegible] with a flaming torch, burn so violently, that even the [illegible] and the sand burn, while actually in the water; this fire [illegible] by rain. If a person makes furrows in the ground with a [illegible] been kindled at this fire, it is said that a stream of flame [illegible] The summit of Cophantus, in Bactria, burns during the night [illegible] the case in Media and at Sittacene, on the borders of Persia;

likewise in Susa, at the White Tower, from fifteen apertures, the greatest of which also burns in the daytime. The plain of Babylon throws up flame from a place like a fish-pond, an acre in extent. Near Hesperium, a mountain of the Æthiopians, the fields shine in the night-time like stars; the same thing takes place in the territory of the Megalopolitani. This fire, however, is internal, mild, and not burning the foliage of a dense wood which is over it. There is also the crater of Nymphæum, which is always burning, in the neighbourhood of a cold fountain, and which, according to Theopompus, presages direful calamities to the inhabitants of Apollonia. It is increased by rain, and it throws out bitumen, which, becoming mixed with the fountain, renders it unfit to be tasted; it is, at other times, the weakest of all the bitumens. But what are these compared to other wonders? Hiera, one of the Æolian isles, in the middle of the sea, near Italy, together with the sea itself, during the Social war, burned for several days, until expiation was made, by a deputation from the senate. There is a hill in Æthiopia called Θεῶν ὄχημα, which burns with the greatest violence, throwing out flame that consumes everything, like the sun. In so many places, and with so many fires, does nature burn the earth!"

"CHAP. III (107)—WONDERS OF FIRE ALONE.

"But since this one element is of so prolific a nature as to produce itself, and to increase from the smallest spark, what must we suppose will be the effect of all those funeral piles of the earth? What must be the nature of that thing, which, in all parts of the world, supplies this most greedy voracity without destroying itself? To these fires must be added those innumerable stars and the great sun itself. There are also the fires made by men, those which are innate in certain kinds of stone, those produced by the friction of wood, and those in the clouds, which give rise to lightning. It really exceeds all other wonders, that one single day should pass in which everything is not consumed, especially when we reflect that concave mirrors placed opposite to the sun's rays produce a flame more readily than any other kind of fire; and that numerous small but natural fires abound everywhere. In Nymphæum there issues from a rock a fire which is kindled by rain; it also issues from the waters of the Scantia. This indeed is a feeble flame, since it passes off, remaining only a short time on any body to which it is applied: an ash tree, which overshadows this fiery spring, remains always green. In the territory of Mutina fire issues from the ground on the days that are consecrated to Vulcan. It is stated by some authors, that if a burning body falls on the fields below Aricia, the ground is set on fire; and that the stones in the territory of the Sabines and of the Sidicini, if they be oiled, burn with flame. In Egnatia, a town of Salentinum, there is a sacred stone upon which, when wood is placed, flame immediately bursts forth. In the altar of Juno Lacinia, which is in the open air, the ashes remain unmoved, although the winds may be blowing from all quarters.

"It appears also that there are sudden fires both in waters and even in the human body; that the whole Lake Thrasymenus was on fire; that when Servius Tullius, while a child, was sleeping flame darted out from his head; and Valerius Antias informs us, that the same flame appeared about L.

Marcius, when he was pronouncing the funeral oration over the Scipios, who were killed in Spain; and exhorting the soldiers to avenge their death. I shall presently mention more facts of this nature, and in a more distinct manner; in this place these wonders are mixed up with other subjects. But my mind, having carried me beyond the mere interpretation of nature, is anxious to lead, as it were by the hand, the thoughts of my readers over the whole globe."

In Book III., Chapter 14, Pliny discusses the volcanoes in the Æolian Islands. Book iv., Chapter 6, contains an account of Achaia, in which Pliny mentions the destruction of Helike and Bura, and the towns in which the people who escaped the inundation of the sea afterwards took refuge. After enumerating the cities of Achaia he adds:

"Throughout the whole of this region, as though nature had been desirous to compensate for the inroads of the sea, seventy-six mountains raise their lofty heads." (Book iv., Chap. 10.)

Pliny has the following remarks on the island of Delos (Lib. IV Chap. 22, pp. 318–319):

"This island long floated on the waves, and, as tradition says, was t only one that had never experienced an earthquake, down to the time M. Varro; Mucianus however has informed us, that it has been twice visited. Aristotle states that this island received its name from the fac its having so suddenly made its appearance on emerging from the [illegible]osthenes, however, gives it the name of Cynthia, and others of Or[illegible] [illegible]Chlamydia, Cynthus, and from the circumstance of fir[illegible] [illegible]rpile. Its circumference is five miles

Rome came very near the true theory of earthquakes as we conceive it to-day?

V. On the Ancient and Modern Theory of Earthquakes, on the Sinking of Helike, and on the Movements Taking Place in the Ægean and Asia Minor.

§ 22. *Common Views of Plato, Aristotle, Strabo and Pliny.*

From the accounts quoted in the foregoing extracts, we have seen that Plato held that air and water, entering through hollows and crevices, obtained access to the bowels of the earth, and that there are everywhere beneath the earth rivers and lakes of fire (Pyriphlegethon), some of which he had seen emitted from Mt. Ætna. Owing to his pictorial style of exposition Plato's accounts are more or less allegorical, but these general results seem sufficiently clear to be beyond doubt. Aristotle was trained under Plato, but he afterwards departed from the style of composition employed in the Academy, and adopted in all his mature writings the modern scientific method of simple direct statement of facts.

Accordingly in the writings of Aristotle we see the theory of earthquakes as taught by the master mind during the culmination of the physical philosophy of the Greeks. Aristotle was not only the greatest natural philosopher of Greece, but of antiquity, and one of the most luminous intellects of all time. No other mind of any age or country has exerted so great an influence on scientific thought or on its terminology. Thus Eusebius designates him as "Nature's private Secretary," while Dante calls him the "master of those who know," in reference no doubt especially to his development of the methods of logic. But Aristotle's genius extended to every branch of human knowledge, and ornamented everything it touched.

In spite of some errors, incident to the early age in which he lived, his observations of nature show the highest order of sagacity and mental penetration, and will always give him the foremost place among the philosophers of antiquity. In his mental activity he felt the necessity for physical laws, and thus became accustomed to seek the *causes* of things; so that in Strabo we find complaint of his depth of thought. His mind was therefore preëminently scientific in the highest sense of the word, and no modern thinker has surpassed him in subtileness and power of intuition.

Like Plato he recognized water and air as entering into the bowels of the globe, through hollows, caverns and fissures; and there, in contact with the internal heat, giving rise to imprisoned vapor, which develops such force that it brings on an earthquake. He fully recognized the prevalence of earthquakes in maritime regions, and on this point his views have been adopted by Strabo and Pliny.

In the time of Aristotle the universe was conceived as made up of four elements, fire, air, water, and earth. But the Greeks noticed the evaporation of water, and its precipitation from the clouds in the form of rain, hail and snow; and they recognized that there was some process by which it became invisible, and was afterwards condensed into clouds and precipitated by atmospheric agencies. Aristotle does not usually distinguish vapor of steam from air, though occasionally he calls steam ἀτμίς, while ordinary wind is called ἄνεμος. He must have conceived the two vapors as passing by some unknown process one into the other.

Accordingly when he says vapor, air, or wind, we are often to understand not only atmospheric air, but also a mixture of vapor of steam. Since such vapor is seen to be emitted by volcanoes, as in the case he mentions of the Æolian Island Hiera, now called Vulcano, he naturally and correctly reasons that it was the cause of that violent outbreak.[1] In like manner Aristotle holds that vapor is the cause of the agitation of the earth even when no surface eruption occurs. He recognized therefore that the tension of elastic vapor seeking to diffuse itself in the atmosphere may become so powerful as to overcome the confining rocks of the earth's crust and bring on an earthquake, even though none escapes to the surface, but the whole of it remains hidden in the earth. In this view he is followed by Lucretius, Strabo, and Pliny. How much more

[1] Paulus Orosius (Lib. LV., Cap. 20) says that this island, which was often called Thermessa by the ancients, arose from the sea in the year 571 B.C. A passage in Thucydides (Lib. III., § 88) shows that it was in existence in 427 B.C. (cf. Strabo's Geography, Bohn's Transl., vol. 1, p. 417, footnote). This date of 571 B.C. is consistent with the date given by Aristotle. Pliny's statement (Lib. II., Cap. 89; Vol. 1, p. 118) is incorrect, and may perhaps be explained by a transcriber's error, or by some confusion of Pliny himself. Perhaps Thermessa was confounded with Therasia near Thera.

philosophical and accordant with Newton's rule this is than the singular modern method of dividing earthquakes into two separate classes, volcanic and tectonic!

Aristotle holds not only that earthquakes are due to vapor in the earth, but also that they are most prevalent near the sea. In other parts of the "Meteorology" (Lib. I, Cap. iv.), he says that the "distribution of land and sea in particular regions does not endure throughout all time, but it becomes sea in those parts where it was land, and again it becomes land where it was sea"; and finally adds "everything changes in the course of time." Aristotle also correctly associated seismic sea waves with earthquakes, and points out cases of islands and volcanoes upheaved in the sea. The philosophical position which he occupied was thus extraordinarily advanced, and there is little wonder that his views were adopted and elaborated by Strabo and Pliny. This simple and orderly development of thought among the ancients is in melancholy contrast to the disconnected and anachronous views still prevalent on these subjects in our own time.

§ 23. *Explanation of the Sinking of Helike and destruction of Bura, 373 B.C.*

We have seen that Strabo says that Helike sank in the night,[1] after the region had been shaken by a great earthquake. He says Helike was 12 stadia from the sea, and Bura 40 stadia, about 1.5 and 5 miles respectively. In his large work on the "Face of the Earth" (Vol. II., pp. 448, 464) Professor Suess explains this sinking by the shaking down of an alluvial deposit, which broke loose from the older formation, thus causing it to slip into the sea. The process described by Suess is a familiar one where a narrow band of soil is formed near steep cliffs; but this shaking lose ob[illegible] could not occur where the extent of the deposit is from [illegible] miles in width. No alluvial deposit of this width would [illegible] an earthquake, unless it was on the slope of a com[illegible] steep mountain, and the strata under it were inclined at a [illegible] of say 30°, which was not the case in the region of [illegible] Bura. These cities were both built on decidedly solid [illegible] along the seashore, and with such a broad base the al[illegible] would not slide into the sea. What J. Schmidt ob-

[1] [illegible] Heracleides.

served in the same region after the earthquake which shook Ægion, December 26, 1861, may possibly have been due to the settlement of the alluvium, but it is much more probable that it arose from a sinking of the crust along the line of a hidden fault, similar to that which so severely rent the ground under Bura in 373 B.C.

It is usually stated that Bura was covered by the sea like Helike, but some of the ancient authors correctly imply that the ruin was mainly due to the opening of fissures of the earth, which caused the houses to be engulfed. Others say that it was also covered by the sea, but both here and at Helike some objects remained above the water. Bura, however, was built on a hill and ruins of it are still extant at considerable elevation above the sea level.

The land which sank when Helike was submerged beneath the waves was evidently similar to that now seen along the southern shore of the gulf of Corinth. A railroad now traverses this shore almost the entire length of the gulf. While on a visit to Delphi early in April, 1891, the writer crossed the gulf in a sail boat, and took the train for Olympia near this ancient site of Helike and Bura. The lay of the land is gentle and nowhere is the ascent other than very gradual. The mountains of Arcadia are quite a distance away, but usually visible to the traveler. From my own observations of the southern shore of the gulf, along the region where Helike now lies beneath the waves, I feel sure that the land of this entire region is too solid to experience appreciable settling under the shaking of an earthquake. What then was the cause of the disaster of 373 B.C.?

In the paper on the cause of earthquakes, we have seen that in world-shaking seismic disturbances lava moves beneath the crust, and usually is expelled from under the bed of the sea. After the crust is thus undermined, the sea bottom frequently subsides, and the sinking of the bed of the sea draws the water away from the shore and causes the seismic sea waves. The gulf of Corinth is a sea trough, with high mountains on both sides; and in 373 B.C. lava was expelled from under it and pushed under the mountains to the north or south—most likely under the Arcadian mountains to the south; and after the lava was expelled the bed of the trough sank down, carrying with it the shores on which Helike stood.

The mountains north of Delphi, including Parnassus and Helicon, as well as those further west in Ætolia, like those to the south in Arcadia, have all been pushed up by the expulsion of lava from beneath the gulf of Corinth. Now the accounts of the destruction of Helike show that the region was first terribly shaken by an earthquake, obviously by the movement of lava streams beneath the crust, what Plato would perhaps call Pyriphlegethon, and then inundated by the sea, the town afterwards remaining largely or wholly under water. This can only mean that the bottom of the gulf gave down, and carried the southern shore down with it; perhaps the fault which moved is beneath the deep soil and did not show at the surface, except in the chasms which appeared at Bura, as mentioned by Aristotle. If alluvium of such great age could settle at all under the shaking of an earthquake, the amount of the subsidence could not exceed a very few feet. This was found to be true of the soft land at San Francisco which had been made within a quarter of a century before the great earthquake of April 18, 1906, and the same conclusion is drawn from observations of many other great earthquakes of recent years. Such shaking down would not be adequate to account for the submergence of Helike beneath the waves.

This town could hardly have been less than 50 feet above the sea level of the gulf, and a height of 80 feet is much more probable, owing to the universal custom of the Greeks of building a town always on the highest available point and crowning it with an Acropolis, containing the temples of the gods. The houses would be at least 20 feet high, so that the subsidence must have been at least 70 feet, and it was more probably from 80 to 100 feet. The amount of the subsidence, even if we take the lowest figure, 70 feet, is altogether too great to be accounted for by mere shaking down of alluvium deposited hundreds of thousands of years ago. And the distance from the sea mentioned by Strabo, who could not well be mistaken, shows that a sliding of the whole broad alluvial deposit could not have taken place.

Moreover, the account given by Aristotle, within whose lifetime the event had occurred, implies that the seismic sea wave was of that class in which the water first retires from the shore (πρόωσις)

and then returns after the currents have met and raised a ridg in the centre of the depression. By no possibility can we interpre Aristotle's account to indicate an elevation of the sea bottom, a when a volcano is upheaved, which would cause the waters to ris suddenly without previous recession from the shore. The onl other class of sea waves is that in which the water retires after th earthquake, and Aristotle's language distinctly implies that this re cession took place. Moreover, Strabo says that the disaster wa attributed to the anger of Poseidon, "the earth-shaker," to whon were ascribed the sea waves accompanying great earthquakes.

If this view be admissible, it will follow that the sinking o Helike was by the usual process of subsidence in seismic sea wave of the first class, except that the subsidence of the bottom of th gulf carried down also part of the shore. As the gulf is quit narrow such a result is probable in the highest degree.

This sinking of the shore along the bed of the sea is nc unusual even where the sea is wide; but for the sake of conver ience of diction we have ordinarily spoken only of the sinking c the sea bottom rather than of the land along the shore. Unle there is movement of a fault with vertical walls, the change of lev is naturally gradual, depending on the yielding and flexure of th earth's crust when lava is injected or expelled from beneath it.

§ 24. *Further Considerations on the Elevation of the Himalaya Based on the Relief of the Indian Ocean at its Margins.*

In the paper on the cause of earthquakes we have explained t Himalayas by the expulsion of lava from beneath the Indian Ocea and have attributed the continuance of earthquakes in that regi to the activity of the ancient sea trough where the Ganges a Bramaputra now flow. The process there is similar to that fou in the Andes, but the mountains are now somewhat further fro the sea. In calling attention to the surface leakage in the regio south of the Himalayas, there was no thought of implying that the effect of the ocean has ceased; on the contrary there can be no doubt that strain beneath the Indian Ocean's crust is still relieved by the same movements which originally formed and are still raising the Himalaya mountains. The surface waters augment the effects of the relief of strain from beneath the sea, and these two

causes together produce the observed earthquakes. This explains the occurrence of a large earthquake belt south of the Himalayas, the existence of which heretofore has been so perplexing. Where the crust is badly broken and fissured, the surface water more readily aids the original tendency to relief, depending on the secular leakage of the adjacent ocean. We have treated this question in section 20 of the paper on the cause of earthquakes, but the Himalayas were not treated in great detail, and it seemed well to point out specifically that the same tendency to relief, which we find around the margins of the Pacific, holds equally true in the great western extension known as the Indian Ocean. Here at present relief is obtained chiefly along the northern and northeastern borders, though some is afforded in islands and various other places. The Indian Ocean not only has high mountains on its margins, but also a considerable number of islands and volcanoes. In this respect it resembles the Pacific.

A study of the principal mountain chains suggests that whenever a serious break has once occurred in the crust of the earth, the strain arising in the underlying layer continues to find relief by the escape of steam-saturated lava into the avenue thus opened, which is the path of least resistance. The formation of the Alps, Andes and other mountains, as well as the Himalayas, illustrate this principle.

Whether the motion of lava towards the avenue of escape is by creeping flow, or by small earthquakes, we do not know; possibly it may be by both methods. It is only in violent world-shaking earthquakes that we can be sure that lava is moved beneath the crust *en mass* over considerable distances. These streams of lava are proved to exist by the uplift of coasts and by the sinking of the sea bottom implied in seismic sea waves.

Such subterranean movements correspond closely to Plato's Pyriphlegethon, but when once a fault has moved for a long time upward, the strain may become so great from the way in which the blocks of the earth's crust are wedged together, that the upward movement there becomes more difficult, and a neighboring region affords easier relief. And in pushing up the neighboring area, the previously elevated block may be let down again, by the relief

thereby afforded beneath. Thus a mountain system such a
Himalayas, Alps or Andes represents a vast number of suc
vations and depressions, and this is the way in which such
ments are to be explained. A theory which is capable of furn
such a simple explanation of such complex phenomena
have a strong claim to acceptance.

The principal escapes from the Indian Ocean seem to be
under the mouths of the Ganges and Indus, and hence we se
these regions are so often disturbed by violent earthquakes.
noticeable that few important changes of level have been pro
there, except subsidence, because these troughs were arched
ward, and the surface movement therefore usually has been

Some geologists have inferred that earthquakes are co
in the deltas of all great rivers. But observation shows tha
is not universally, nor even commonly, true. The deltas
Mississippi and Amazon, so far as known, have never exper
severe earthquakes, and if deposits of sediment were the
they ought to have felt disturbances like those which have
frequent in the deltas of the Ganges and Indus. But there
important difference between the Ganges and the Indus, on tl
hand, and the Mississippi and Amazon on the other. Und
former are avenues of escape for the steam-saturated lava fc
under the Indian Ocean, while little if any escape takes pl
the mouth of the Mississippi and Amazon. The Gulf of M
is only moderately deep and the crust broken and faulted
on the side towards Mexico, hence the earthquakes occur
the Atlantic in the region of the Amazon is shallow, and the
along the coast but little broken.

It appears therefore that the claim that earthquakes oc
the deltas of great rivers must be given up. Thus we get
clearer view of the relief of the Indian Ocean, by which the
layas were formed; and the earthquakes occuring there no
come more intelligible.

§ 24. *On Professor Suess' Theory that the Ægean Sea ha*
lapsed within Recent Geological Time, and on the Origi
Secular Movements of Asia Minor and Syria.

Professor Suess holds that the basin of the Ægean Sea ha

down in recent geological time; and on the assumption that the globe is shrinking, he thinks the whole of Asia Minor may some day collapse, and thus connect the Pontus and the Caspian directly with the Mediterranean. According to the view here adopted nothing could be further from the truth than such an hypothesis. For, in the first place, we have shown that as the effect of cooling is insensible, the earth is not contracting; and, in the second place, that the movements of the crust are due to the action of a substratum just beneath, which in earthquakes behaves as fluid.

Moreover, the relative situation of the rocks about the Ægean Sea will be the same whether that sea has recently sunk down, or the whole of Asia Minor has been raised up. There is no historical evidence of the sinking of the Ægean Sea, except that furnished by the disturbances due to earthquakes, and the geological evidence is capable of a double interpretation. The prevalence of earthquakes in Asia Minor is a proof that subterranean movement is now going on there; otherwise such places as Apamea in Phrygia, Smyrna, Mitilene, Antioch and numerous other cities would not have suffered so much from earthquakes within historical times. The whole coast of Asia Minor and of Syria has been subject to severe earthquakes since the earliest ages; and the ruins of temples at such places as Palmyra and Balbec are to be explained partly by the effects of political revolutions and partly by the ravages of time, but more especially by the leveling influence of earthquakes.

In his work on "Earthquakes in the Light of the new Seismology," Major Dutton gives an account of the different kinds of seismic sea waves, and remarks that those in the eastern Mediterranean have usually been characterized by a preliminary withdrawal of the water before the wave returns to inundate the shore. Such waves are the only kind mentioned by Aristotle, which shows that they were familiar to the Greeks at an early age.

Now if the waves are predominantly of this class, just as along the west coast of South America, it follows that the sea bottom sinks, and has therefore been undermined in the process of elevating the mountains and the coasts. Asia Minor and Syria are covered with mountains of a complex character, and many movements of these mountains have been observed within the period

covered by history. No doubt the general movement is one of elevation, which corresponds to the sinking of the sea bottom implied in the seismic sea waves observed to come ashore after the terrible earthquakes by which the region is afflicted.

As the mountains are of recent formation, and extend entirely across Asia Minor, we may not hesitate in the belief that the whole of that region has been elevated within recent geological time. The sinking of the sea bottom prevailing in that part of the Mediterranean has often carried down the shores with it; but in a number of cases elevation has also taken place. Strabo, among the ancients, gives evidence bearing on this question; and Professor Suess, among the moderns, cites important changes which have taken place since the age of the Greeks. In "The Face of the Earth" (Vol. II., pp. 448–453), Suess mentions the subsidence of Smyrna and of the famous mausoleum in the Bay of Makri, as well as changes of level at Mitylene, Mermiridje and other places. It would be moderate to say that his explanations seem highly improbable, and it is really impossible that all of them can be correct. They rest on no general principle, but rather on improvised hypotheses.

The mausoleum at Makri can hardly have slid with the alluvial soil into the bay, as he maintains; for, judging by the photograph of the mauseleum which he gives, the alluvial base is not less than a mile wide, and thus would not slip, unless the substratum of rock were greatly inclined, which does not seem to be the case. The adjacent sea appears to be shallow, and all these circumstances are against the theory. Finally it is unlikely that the alluvium could be sufficiently settled by an earthquake to bring the mausoleum down to the level of the water, so that the tides would cover the lower part of it. It must have stood originally not less than 20 feet above the sea level, and 60 feet is a much more probable elevation. It is thus practically certain that the shore was carried down in the subsidence of the sea bottom, as happened when Helike sank beneath the waves in B. C. 373. In the case of the mausoleum the submergence may have been either sudden, or gradual. Darwin and Fitzroy observed the Chilean coast to subside slowly after it had been pushed up by the earthquake of 1835, and these slow move-

ments frequently occur, but are seldom recorded, because so much less obvious than sudden changes of level. In this way we may explain the changes of level at the Troad, Ephesus, the Peireus and other places mentioned by Strabo.

In the "Face of the Earth" (Vol. II., pp. 450–451), Professor Suess discusses the supposed changes in the level of the coast road on the Climax mountains in Pamphylia; and quotes Luschan, who says that "the sandy ground at the foot of these steep cliffs, which formerly offered a practicable road, is now (January, 1885) covered by the sea to a depth of four metres."

Here is Strabo's detailed description of this road as it was in the time of Alexander:

"About Phaselis, near the sea, are narrow passes through which Alexander conducted his army. There is a mountain called Climax. It overhangs the sea of Pamphylia, leaving a narrow road along the coast, which in calm weather is not covered with water, and travelers can pass along it, but when the sea is rough, it is in a great measure hidden by the waves. The pass over the mountains is circuitous and steep, but in fair weather persons travel on the road along the shore. Alexander came there when there was a storm, and, trusting generally to fortune, set out before the sea had receded, and the soldiers marched during the whole day up to the middle of the body in water." (Strabo's "Geography," Bohn's transl., Vol. III., p. 48.)

When one reads this clear and definite account, can there be any doubt of a subsidence since Strabo's time? In the campaigns of Alexander the soldiers did not march through more than one metre of water even during a storm; now the water is four metres deep, and if we could conceive the tallest of Alexander's soldiers raised to double height, by one standing on another's head, even the upper one could not keep his head above water. A subsidence therefore is undeniable, for a road would never have been thought of in four metres of water. It cannot be explained by a settlement of the road bed, which is mainly of stone, and gravel, covered with a thin layer of sand deposited by the waves; nor by the shaking down of the base during an earthquake, for such subsidences would be very small, and probably unequal at different points. It can have resulted only from the uniform sinking of the coast by at least three metres. This then is a well authenticated case of subsidence within the historical period.

It is impossible that all of the landslips assumed by Professor Suess to account for the numerous ruins beneath the sea, in Italy, Greece and Asia Minor, can be real; for as a rule such slips would depend on the breadth of the base, and the dip of the underlying strata. Unless the dip is very steep, sliding with a broad base is nearly impossible. Even with abundant underground water, the sliding of a broad mass is very difficult, for there will be rocks or obstructions somewhere which hold it fast. We have already remarked in regard to the mausoleum of Makri that the photograph given by Professor Suess (Vol. II., p. 449) shows that the alluvium is about a mile wide, and very flat. As the adjacent sea seems to be shallow, such a broad mass could not slide into it by the shakings of an earthquake. On the contrary it is clear that the coast sank and carried down the mausoleum with it, so that it is now washed by the tides and waves.

In conclusion we may hold that the Ægean sea probably is rising, and that within recent geological time Asia Minor and Syria have been raised from the sea; so that the Pontus and Caspian were formerly continuations of the Mediterranean, but are now cut off by the secular movement of the earth's crust. Many volcanoes have formerly been active in Asia Minor and Syria, which shows that geologically the region is one of elevation. Lava from beneath the Mediterranean, as well as the Pontus and Caspian, escapes under this region, and in the sinking of the sea bottom the shore is sometimes carried down with it, as in Pamphylia and other places which we have discussed. But in the course of geological ages movement of elevation predominates. Unless this were true, it is highly improbable that the whole region between the Mediterranean, Pontus and Caspian would be so powerfully afflicted by earthquakes.[1]

[1] Since this paper was finished a severe earthquake has occurred at Bitlis in the mountains of Armenia. A press dispatch of April 4, from Constantinople, gives the following report from the Rev. Roy T. Lee, head of the American Mission at Bitlis:

"At ten o'clock in the forenoon of March twenty-ninth there burst upon us unannounced the worst earthquake experienced in forty years in these or the Ezerum volcanic regions. Such was its force that our city seemed to be in the jaws of some monster who would shake us into shreds as some mastiff does his game. Down came the plastering, the furniture was over-

There remains the possibility that the Ægean is being undermined by the expulsion of lava from beneath it, and it might be sinking so long as this process is at work; but it is difficult to doubt that the ultimate destiny of the Ægean is to be raised above the sea and become dry land, thus completing the bridge between Europe and Asia Minor. This general result is indicated by a study of the map. The numerous islands in the Ægean contradict the theory of permanent subsidence. The volcano which used to be active in the island of Lemnos, the eruptions in Eubæa mentioned by Strabo, the elevation of the Island of Delos, the repeated outbreaks near Thera, the numerous small islands which have been reaised in the sea within the historical period,—all these phenomena point to elevatory movement affecting this whole region, because volcanic activity usually shows itself in regions of elevation. It is hardly possible that these several signs of elevation would have appeared if the Aegean were in process of secular subsidence. The activity of Mt. Ararat within historical time, especially in 1840, and of Mt. Demavend, south of the Caspian, and the outbreaks from other volcanoes in Asia Minor, all point in the same direction, and render it probable not only that the region is geologically one of elevation, but also that the Pontus and Caspian were thus cut off from the Mediterranean. The Dead Sea and the valley of the Jordan were cut off in like manner, and by this very earthquake process which has so often afflicted Syria within the period covered by human history.

The mountains in Syria parallel to the Mediterranean east coast, like those in Epirus and Dalmatia so beautifully parallel to the northeast shore of the Adriatic, were as clearly formed by the Mediterranean as the Andes, Rocky Mountains and Sierras were by the Pacific, which for millions of years has been uplifting a hemisphere unknown to the ancients.

As bearing on the subterranean processes at work under the Ægean Sea, by which Olympus and all the surrounding mountains

turned, cracks were opened in strong walls, roofs were shattered and the rain poured in." In this case lava streams were evidently readjusting themselves under the earth's crust. The comparison of the shaking to that which a mastiff gives his game is most appropriate. It was just such shaking that proved so disastrous at San Francisco, Valparaiso, Kingston, and other places where lava was adjusting itself under the crust.

were formed, and repeatedly disturbed by earthshaking Poseidon, the following passages in Homer will not be without interest. The partition of the world among the principal deities is thus explained by Poseidon himself:

"For we are three brothers (descended) from Kronos, whom Rhea brought forth, Zeus and I and Pluto, governing the infernal regions, the third; all things were divided into three parts, and each was alloted his dignity; I in the first place when the lots were shaken was assigned to inhabit forever the hoary sea, and Pluto next obtained the pitchy darkness; and finally Zeus received the wide heavens in the air and the clouds; but the earth is still the common property of all, and lofty Olympus." (Iliad, XV., 187–194.)

The account describing Poseidon's mansions beneath the Ægean sea is as follows:

"Nor did king Poseidon keep a vain watch; for he sat aloft upon the highest summit of the woody Thracian Samos, admiring the war and the battle. For from thence all Ida was visible, and the city of Priam was visible, and the ships of the Greeks. Then coming out of the sea, he sat down, and he pitied the Greeks, subdued by the Trojans, and was very indignant with Jove. But presently he descended down from the rugged mountains, rapidly advancing on foot, and the high hills and woods trembled beneath the immortal feet of Poseidon, advancing. Thrice indeed he strode, advancing, and with the fourth step he reached Ægæ, his destined goal. There distinguished mansions, golden, glittering, ever incorruptible, were erected to him in the depths of the sea. Coming thither, he yoked beneath his chariot the brazen footed steeds, swiftly flying, crested with golden manes. But he himself placed gold about his person, took his golden lash, well wrought, and ascended his chariot. He proceeded to drive over the billows and the monsters of the deep sported beneath him on all sides from their recesses, nor were ignorant of their king. For joy the sea separated; and they flew very rapidly, nor was the brazen axle moist beneath. And his well-bounding steeds bore him to the ships of the Greeks.

"Now there is an ample cave in the recesses of the deep sea, between Tenedos and rugged Imbrus. There earthshaking Poseidon stopped his horses, loosing them from the chariot and cast beside (them) ambrosial fodder to eat." (Iliad, XIII., 10–35; Buckley's Translation.)

The Ægean Sea was the part of the Mediterranean with which Homer was best acquainted, yet he possessed fairly accurate knowledge of many seas and many lands; and the fact that out of all this domain of ocean he placed Poseidon's chief abode beneath the Ægean indicates that if he did not possess divine wisdom, with regard to earthquake forces, he at least chose for the earthshaker's dominions the very spot which would be selected to-day, in the light of the history of thirty centuries since the composition of the Iliad.

VI. Conclusions.

It now remains to sum up very briefly the chief conclusions at which we have arrived. Different arguments appeal with unequal force to different minds, and doubtless there are some who will hesitate at departing from the views recently current in the sciences which deal with the earth. Others who have more or less despaired of definite results under the uncertainty and confusion heretofore existing, will naturally be slow to believe that the laws and order of nature are so simple. But these varieties of temperament will not change the force of the several arguments for a single cause shown to underly the most varied phenomena.

We have endeavored to show not only that the cause assigned in the paper on earthquakes is adequate to account for the observed phenomena, but also, through the process of exclusion, that no other possible cause is at work in world-shaking earthquakes. In this survey of the whole field we were led to reject the theory of contraction and secular cooling as an effective agency in modifying the surface of the earth. And we contrasted the absence of world-shaking earthquakes in an inland region like Colorado and Kansas or the Desert of Sahara with their constant occurrence along the Andes, as a proof that the forces involved depend on the ocean and not at all on secular cooling. For if this latter is a real cause it should be at work inland as well as along the sea coasts. These considerations therefore seem to establish the cause which has formed mountains, and wrinkled the earth's crust in a very complicated manner.

In the study of this question consideration was carefully restricted to earthquakes of the world-shaking class, because the great disturbances were held to be best adapted to disclosing the true nature of the processes hidden beneath the earth's surface. The problem was thus simplified and cleared of the confusion that would necessarily have resulted from the simultaneous consideration of all earthquakes, ..th large and small.[1] The slight shocks may be due to various

[1] Viewing the earth as an elastic solid under stresses of varying inten-..y several eminent mathematical physicists have recently considered the ..tational stability, or the stability of the crust under its own gravitation, ..n some of the surface matter is removed. After calculating these hypo-..ical effects by elegant mathematical methods, some of them have in-..d that when denudation takes place under geological agencies, thus

causes, but are mainly traceable to the effects of great earthquakes of the present and past, which have left the earth's crust much broken and distorted and often in an unstable condition.

This is clearly shown by the after-shocks which follow world-shaking earthquakes in great numbers and for a long time. Thus nearly all earthquakes result directly or indirectly from the great earthquakes; but the movement in different cases is doubtless very different, and consists largely in the gradual adjustment of the disturbed crust. Hence our principal conclusions are the following:

1. The cause of world-shaking earthquakes, mountain formation, and kindred phenomena connected with the physics of the earth, is the secular leakage of the ocean bottoms, which gives rise to the development of steam beneath the earth's crust.

2. This vapor and no other is the cause of these disturbances, because if any other vapor were at work beneath the crust some of it would escape through the vents of volcanoes, and become recognizable by observation.

lowering the level, the crust, having the weight at length removed, would spring upward, perhaps recovering much or all of the elevation lost by denudation. The following considerations will show that this reasoning as applied to geology is likely to be fallacious. Under ordinary conditions denudation is very slow, and the unloading too gradual to produce anything but the most insensible relief upward. We can see that this will be true by considering how little a corresponding increase of load would sag the level. If for example the load be a mass of soil or of rock 100 feet deep, the sagging where the ground is hard, but not solid rock, would be of the order of a few inches. The removal of such a load would no doubt give rise to a similar restitution upward, but no more; and as such denudation in nature is excessively slow, the springing upward is infinitesimal, and requires nearly infinite time. Therefore no important geological effects depend on such causes, though perhaps insensible surface movements may thus arise. But they would scarcely claim the title of microseisms and certainly could not rise to the dignity of earthquakes; for even if landslides should occasionally develop in this way the resulting shocks would be mere local tremors. No heavy earthquakes could depend on such causes, for if so they should be observed far inland as well as along the sea coast, which is contrary to observation. Accordingly while such reasoning is learned, and mathematically interesting, it has only a slight physical basis, and as applied to geology is deceptive and misleading. Until the true cause of world shaking earthquakes is placed beyond doubt and fully recognized, the consideration of such infinitesimal influences as this had better be passed over, because it simply bewilders the subject. In this connection particular attention is called to the footnote on pp. 408–409 of the paper on the cause of earthquakes.

3. The distribution of volcanoes, mountains, and earthquakes shows that all these phenomena depend upon the sea and water generally; wherefore the depth of earthquakes is shallow and so far as is known never exceeds forty miles.

4. The principal purpose of earthquakes is the elevation of land, which has made possible the development of the higher forms of life upon the earth.

5. Plato, Aristotle, Strabo and Pliny all held that water and air penetrate into the earth, through hollows, fissures and crevices, thus developing vapor in the heated interior, a part of which is expelled from volcanoes. And they also held that earthquakes are due to the tension of elastic vapors seeking to escape and diffuse themselves in the atmosphere, whether these vapors break through and form eruptions, or remains hidden in the earth.

6. The movement of streams of lava beneath the earth's crust, which occurs in every world-shaking earthquake, is the modern view of Plato's Pyriphlegethon. Though Aristotle and his successors associated earthquakes with the sea, they do not appear to have held any definite theory of the movement of the fluid beneath the earth's crust. From Strabo's remarks, however, it appears probable that they considered mountains to be formed by earthquakes and eruptions.

7. Aristotle correctly associated seismic sea waves with earthquakes; and even Homer assigned these great disturbances of the sea to Poseidon's trident, which was also the means employed for raising up islands from the bottom.

8. The withdrawal of the water from the shore after an earthquake and its return as a great wave, was familiar to Aristotle, and is implied in his description of the sinking of Helike in 373 B.C.

9. This pathetic calamity was due to the subsidence of a portion of the sea bottom in the gulf of Corinth, after lava had been expelled from beneath it, and pushed under the mountains of Arcadia.

10. The elevation and subsidence of the land long ago contended for by Strabo is now proved to occur, and examples of this movement may be cited in ancient as well as in modern times. While Strabo clearly states the fact of such movement he seems to have been doubtful of the cause. Aristotle does not give the cause of these changes,

though he no doubt associated them with earthquakes and the sea, which seems to be the view also of Plato, so far as one can judge from his description of the sinking of Atlantis.

11. The theory here developed was therefore roughly outlined and more or less anticipated by the leading Greek philosophers, especially by Aristotle; and as formulated by them it continued to be held till modern times, though of late years it has been quite abandoned, owing to the unfortunate development of the theory of tectonic earthquakes.

12. In the present paper we have examined carefully the question of the temperature of the earth, and have given what appears to be the most probable law of its internal distribution.[1] No external effects traceable to deep-seated movements of heat are discoverable, and we have therefore concluded that the nucleus of the globe is now and always has been quiescent.

13. The deformations of the earth's surface are found to be due to earthquake processes working just beneath the crust, and to original inequalities of the surface dating from the genesis of the moon, which gave rise to the principal ocean basins.

14. The two methods for estimating the period since the consolidation of the globe agree in indicating that it was of the order of ten million years, and thus by no means so long as many geologists have been inclined to believe. Moreover, appreciable cooling has not extended below the depth of some forty miles, or one one-hundredth of the radius, so that it is confined almost wholly to the crust.

15. It is estimated that the Andes might be formed in something like three million years, and the plateaus west of the Rocky Mountains in not more than five million years.

16. When the tension of the imprisoned steam under the oceans becomes very great, it finally causes the crust to yield along the margins, [illegible] mountains are pushed up where the crust breaks parallel [illegible] coast. When an avenue of escape is thus once opened [illegible] it continues active, and the mountains grow higher and [illegible] meanwhile the sea recedes to too great a distance.

[1] [illegible]parison of the small figure in the right hand upper corner of the [illegible] the larger figure F shows how one of the distributions of [illegible] passes into the other by continuous flow of the heat outward [illegible] planet is consolidating. The monatomic curve thus becomes an

17. At one time or another the principal oceans form mountains all around them, but in any one geological age the relief may be chiefly on one side, except when the ocean is of very great extent, like the Pacific,[1] which therefore is active all around, and obtains some internal relief by the formation of numerous islands.

18. We have shown that just as soon as the exploding lava acquires sufficient tension or elastic pressure to lift the crust along a fault line, a displacement occurs there, and the lava spreads beneath the block thus moved, giving relief along the path of least resistance. It is the enforced movement of these subterranean lava streams which shakes down cities and devastates whole countries.

19. It is found that secular cooling is so very slow and so small in amount that it has no sensible effect on the physics of the globe. Accordingly it is shown that the earth is not now shrinking, nor has it been at any time since the consolidation began.

20. On the contrary the formation of pumice everywhere beneath the land, as it is elevated by the steam forming under the oceans, is raising the level of the continents, in spite of erosion. And as the oceans are being gradually narrowed by the recession of the sea, after successive mountain chains are formed—some of the water sinking beneath the earth's crust, and the rest collecting into a smaller area, here and there growing deeper when lava is expelled from beneath the margins—it may well be that the ocean level is nearly stationary, or rising slightly with respect to the centre of the earth, though there is a secular lowering of the strand line relatively to the land. Accordingly so far from contracting the earth may be in reality very slightly expanding. This secular expansion is due to the formation of pumice nearly everywhere beneath the crust.

[1] In his *Manual of Geology*, 1863, the late Professor J. D. Dana came surprisingly near many of the views reached in the present investigation. He pointed out with great clearness that the continents not only are built on one model, with the mountains around their borders, while the interior is a depressed basin, but also that the highest border is on the side of the greatest ocean, and conversely. In speaking of this fundamental law he remarks that "the relation between the extent of the oceans and the height and volcanic action, etc., of their borders proves that the amount of force in action had some relation to the size and depth of the ocean basin. The Pacific exhibits its greatness in the lofty mountains and volcanoes which begirt it."

21. The calculated fall of temperature for the whole earth of 10° C. (Tait) and of 45° C. (Daniell) in 100 million years, with the cubical coefficient of expansion of 0.00002, found by experiment for average rock of the earth's crust, would produce a shrinkage of only 0.26 and 1.16 miles respectively. But if the period since the earth's consolidation be only about one tenth that here assumed, according to the usage of geologists, the corresponding contraction would certainly not much exceed one tenth of these values, or say 137 and 612 feet. These values are so very small that the uplifts due to earthquakes might easily cause the globe to expand rather than contract. Accordingly if our present data do not enable us to conclude that the earth is undergoing secular expansion, we may at least conclude that it certainly is not sensibly contracting. Its dimensions seem to have been nearly stationary since the consolidation began.

22. The principal phenomenon heretofore requiring the theory of contraction is the formation of mountains; but Rev. O. Fisher has shown that this cause is quite inadequate, and in the paper on the cause of earthquakes we have developed the theory of mountain formation depending on the sea. The doctrine of the secular contraction of the globe must therefore be entirely abandoned, and the explanation of the phenomena sought in other causes.

23. By the existence of unstable pinnacles of rock formed by the gradual processes of geological time it seems to be proved that no deep and very powerful convulsions of our globe, except the ordinary shocks noticed in earthquakes, have taken place in many millions of years. We must therefore ascribe to ordinary world-shaking earthquakes the highest geological significance. These forces depending on the sea produce both elevations and depressions of the land, and explain all the phenomena of movement witnessed upon the earth.

24. In the development of these views Aristotle and Strabo occupy the foremost places among the ancients; Humboldt, Lyell and Darwin among the moderns; while Fourier and Lord Kelvin naturally claim the leading places among the illustrious physicists who have occupied themselves with these great problems of the heat of our planet.

Blue Ridge on Loutre,
Montgomery City, Missouri, March 22, 1907.

:onclusion it remains[1] to notice one difficulty which has oc- to some readers, and thus should perhaps be given further :ion. By those who have not made a careful study of the r of matter under great fluid pressure, it seems to be felt that standing the apparently conclusive character of Daubrée's ıents, they form a rather slender experimental basis upon o build a satisfactory explanation of the sinking of sea water ı the earth's crust, which is composed of from ten to twenty f solid rock like granite. That this supposed difficulty is of real foundation will appear from the following considera- rhich enable us to show that the oceans do experience such a leakage, and to prove this fact quite independently of e's experiments.

n the paper on the cause of earthquakes, § 15, it is shown that nces are at least (100 billion)^6 or a decillion decillions to one, : mountains are formed parallel to the shore by a true physi- se depending on the oceans. This is of course an absolute y. The mountains therefore depend in some way upon the 'o perceive most clearly what this dependence is, we may as in the former paper, that the elevation of the Andes has :companied by the sinking of the adjacent sea bottom into a trough of about the same volume. That lava has been ex- rom beneath the sea and pushed up under the land is indicated lepression in the sea bottom parallel to the Andean Cordillera; s inference drawn from the geometrical evidence of the sur- the lithosphere is confirmed by direct observations, made the historical period, on those earthquakes which produce : uplifts of the coast and simultaneous subsidences of the sea , as shown by the accompanying seismic sea waves. More- ıbroken continuity between the small uplifts and subsidences :d within the historical period and the vastly greater move- gradually accumulated during past geological ages is estab- ıy the deposits of shells and fossil beds found at great heights Andes, and by the deep depressions in the adjacent oceanic It is therefore undeniable that in the course of long ages

[1] is closing discussion, with the exception of the last sentence, was ıpril 18, 1907.

the mountains and coast have been greatly elevated and the adjacent sea bottom correspondingly sunk down.

2. The earthquake shocks producing these effects are found to occur at a depth of some 15 miles, where the pressure is so great that no cavities in the earth can possibly exist. Therefore there are neither voids at this depth beneath the mountains nor corresponding increases of density beneath the sea where the bottom has subsided, but vast quantities of matter have been expelled from beneath the ocean and pushed up under the adjacent mountains. These phenomena, as observed in South America, are clear and indisputable, and admit of but one interpretation: namely, that the Andes have been formed by successive earthquakes which have expelled the lava from beneath the bed of the adjacent sea, and thus upraised the crust into some of the mightiest mountains of the globe.

3. The next question then becomes: How is the lava expelled from under the sea? We say lava rather than solid rock, because owing to the increase of underground temperature, at a depth of 15 to 20 miles below the surface, where the world-shaking earthquakes originate, the matter must be essentially molten, in spite of the great pressure to which it is subjected. We therefore answer that since the earth is neither contracting nor experiencing any other sensible changes from secular cooling, the expulsion can be accomplished only by explosive vapors such as are emitted from the neighboring volcanoes, which often break out into eruption simultaneously with an earthquake noticed to produce an elevation of the shore and a sinking of the sea bottom. This vapor therefore can be nothing else than common steam.

4. Now the steam developing beneath the earth's crust and producing earthquakes and volcanic activity can be traced to but two possible sources: First, the original magma of the globe, which, in default of a better explanation, has been frequently invoked by the geologist; Second, the secular leakage of the ocean bottoms effected through 15 miles of solid rock like granite, which naturally appeals to the physicist. If the escaping steam, or any sensible part of it, came from the central magma of the globe, volcanoes and earthquakes necessarily would occur in the interior of continents as well as along the coasts, on islands, and in the depths of the sea. For

the continents are large areas, and altogether cover more than one fourth of the total surface of the globe; yet the volcanoes and world-shaking earthquakes are confined to the neighborhood of the oceans or other large bodies of water.

5. It clearly follows therefore that the agitating vapor does not come from the central magma of the globe, but must come from the secular leakage of the ocean bottoms. This is unmistakably indicated by the most overwhelming evidence of nature.[1]

[1] Newton's rules of reasoning in natural philosophy should be borne in mind here:

Rule I. "*We are to admit no more causes of natural things, than such as are both true and sufficient to explain their appearances.*"

"To this purpose the philosophers say, that Nature does nothing in vain, and more is in vain, when less will serve; for Nature is pleased with simplicity and affects not the pomp of superfluous causes."

Rule II. "*Therefore to the same natural effects we must, so far as possible, assign the same causes.*"

"As to respiration in a man, and in a breast; the descent of stones in Europe and in America; the light of our culinary fire and of the sun; the reflection of light in the earth, and in the planets."

Rule III. "*The qualities of bodies, which admit neither intension nor remission of degrees, and which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever.*"

Newton's explanation of this rule is too long to be quoted here; but it is worthy of the most careful study.

Rule IV. "*In experimental philosophy we are to look upon propositions collected by general induction from phenomena as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions.*"

"This rule we must follow that the argument of induction may not be evaded by hypotheses."

In the investigation of the physics of the earth involving many hypotheses of very unequal weight this last rule acquires special importance. If therefore some trifling details are not yet explained or understood we must not on that account reject the cause gathered by a general induction of all the related phenomena of the globe. On the contrary we must adhere to the cause "as accurately or very nearly true, notwithstanding any contrary hypotheses that may be imagined, till such time as other phenomena occur, by which they may either be made more accurate, or liable to exceptions," in order that the "argument of induction may not be evaded by hypotheses." In his explanations of Rule III. Newton remarks: "We certainly are not to relinquish the evidence of experiments for the sake of dreams and vain fictions of our own devising; nor are we to recede from the analogy of Nature which uses to be simple, and always consonant to itself."

fore it incontestably follows that the explosive vapor earthquakes, volcanoes, mountain formation and kindred connected with the physics of the globe, comes from the age of the ocean bottoms, effected through the earth's posed of some fifteen miles of solid rock like granite. ordingly it necessarily follows also that Daubrée's experire applicable to layers of rock twenty miles thick, when the r is subjected to the great fluid pressure constantly operating the deepest oceans. Our fundamental proposition is thus proved te independently of Daubrée's experiments. In fact by simply rving the phenomena of nature one might infer that such experiments as those made by Daubrée would be possible under good laboratory conditions.

8. In the case of our thinly encrusted planet so largely covered with water the natural arrangement between the overlying oceans and the underlying molten globe constitutes a laboratory of the most imposing magnitude, infinitely transcending anything ever conceived by man, with gigantic experiments constantly going on. All that is needed therefore is for the philosopher to interpret nature's stupendous operations, which unfortunately only too often prove disastrous to human life, because of our ignorance and disregard of natural laws. The highest duty of the philosopher is to discover these laws and make them available to the world, so as to contribute as much as possible to the repose and safety of mankind.

9. According to the theory here developed earthquakes and related phenomena, which have so afflicted the world from the earliest ages, are not much to be dreaded when their laws are understood, and adequate precautions are taken to secure the building of safe houses. When, however, people live near active volcanoes protection is not always possible, though fortunately it is generally within reach at most places visited by earthquakes throughout the world.

10. But as great multitudes of people live in cities by the sea they are also subjected to the dangers arising from seismic sea waves; yet if a place of refuge exists they usually have ample time to escape. And even the ships in the harbor will generally be safe if they promptly put to sea on the first sign of the withdrawal of the

water after the earthquake, which always indicates that the sea bottom has sunk. Thus by the study of the laws of the physical world, and the diffusion of the resulting useful knowledge, a great measure of safety may be secured from some of the most dreadful forces in nature, and in the course of time the interests of civilization enormously conserved.

When we reflect over these results and contemplate the harmony thus established in many branches of the physical sciences, is it not obvious that Newton's belief that the great laws of nature are simple may with great advantage still be borne in mind by those who wish to arrive at the ultimate causes which lie at the basis of natural philosophy?

Blue Ridge on Loutre,
Montgomery City, Missouri, April 18, 1907.

Addendum.

Further Considerations on the Earthquake at Helike and Bura, 373 B. C.

Some time after the foregoing was finished it occurred to me to consult Grote's "History of Greece," in the hope of obtaining further light on the famous disaster at Helike; and from his references (Vol. X., p. 157) to Diodorus Siculus, Ælianus and Pausanias I have prepared the following addendum:

1. *Diodorus Siculus, Book XV., Chap. V.*—It is well established that this historian flourished in the reign of Augustus, but the date of his death is not known. The translation here followed is that of G. Booth, London, 1700. This is an old work, and the style of writing is antiquated, but the meaning appears to be clear.

"Afterwards when Asteius was chief magistrate at Athens, and six Military Tribunes, viz. Marcus Furius, Lucius Furius, Aulus Posthumus, Lucius Lucretius, Marcus Fabius and Lucius Posthumus executed the office of Consuls at Rome, there happened such dreadful earthquakes and inundations in Peloponnesus (throughout all the cities and over all the country) that are incredible to relate. For never in any former Ages did the like calamity fall upon the Grecian Cities, which were now swallow'd up together with their inhabitants; and certainly some Divine Power contrived and executed this remarkable ruine and destruction of Mankind: Nay the time when it was done aggravated the greatness of the calamity. For the earthquake hapned not in the day (when the distressed might have found out some way or other to have helped themselves) but in the night; and

when the houses by violence of the shake fell down in confused heaps; so that (by the darkness of the night and the suddenness of the ruine) men were in that perplexity that they knew not which way to turn themselves for security; in so much as the greatest part of the inhabitants (buried in the rubbish of the houses) miserably perished. But as soon as it was day some came running out of the houses, and thinking they had escaped the danger, fell into a far greater and unexpected mischief; for the sea raged to that degree, and broke in with that violence that it swallowed up them and their houses together. Two cities of Achaia, one called Helica and the other Bura, chiefly suffered by this sad accident, of which two Helica was of the greatest account of any of the cities of Achaia.

"There was a very hot dispute concerning the cause of this evil. Indeed the natural philosophers do generally ascribe all such events to Natural Causes, and necessary circumstances, and not to any Divine Hand; But they who have more reverend thoughts and sentiments of a Deity, give a very probable account of this matter, that this destruction was the effect of the Anger of the Gods, for the impious violation of the rights of Religion, of which we shall give a more particular account. . . ."

After describing the impious conduct of the Heliconians, Diodorus continues:

"Upon this they of Helica siezed upon all the goods of the Ionians and committed the Ambassadors to Prison, and so carried it very impiously towards the Deity. Therefore they say Neptune being angry, to revenge himself upon their impiety (by this earthquake and inundation of the sea) brought this grievous calamity upon those cities. And that it was done by him they use this for an argument: *That it is generally believed that this God hath the power of inundations and earthquakes in his own hands;* and that *Peloponnesus* had been ever reputed the Habitation of *Neptune,* and the country dedicated to him and that all the Peloponnesian cities worshipped this God above all others. Besides this, they give a further reason of said accident. There are (as they say) in Peloponnesus great cavities underground, which by the sea flowing here and there through the earth are turned into great Ponds and Lakes of water. And indeed it is very certain that there are two rivers in that Peninsula, which apparently fall into the caverns of the earth. For the Rivers which ran by Pheneum in former Ages sank in one place into the earth, and became invisible, being swallowed in these caverns underground. Another was lost at a great opening of the earth at Stymphius, and ran unseen underground for the space of two hundred stages, and rose again near the city Argos." (Diodorus Siculus, Lib. XV., Cap. V., translated by G. Booth, London, 1700.)

2. *Ælianus, De Natura Animalium.*—This well known author probably flourished in the time of the Emperor Hadrian. His account of the earthquake at Helike is short but very clear. As given in Teubner's edition of the works of Ælianus, Leipzig, 1864, the account (xl., 19) runs thus:[1]

[1] Rev. Theodore F. Burnham very kindly verified the translation now offered.

"When a house obviously is about to be overthrown, the mice which are in it leave along with the weasels, and they anticipate the disaster and emigrate. This indeed they say took place also in Helike. For when the Heliconians were engaged in religious worship, upon the arrival of the Ionians, they sacrificed them (the animals) upon the altar, whence forthwith (this is Homeric) certain gods manifested signs unto them; for five days before the disappearance of Helike all the mice that were in it, and weasels and serpents, millipedes and beetles and the rest of things of this kind, crept forth together into the road leading to Cerynea. And the Heliconians seeing what had happened marveled indeed, but were unable to understand the cause. And when the aforementioned animals had left the place, an earthquake occurred in the night, and the city collapsed, and, overflown by a great wave, Helike disappeared; and by chance ten vessels of the Lacedemonians lying at anchor perished in the rush of the waters. And it came to pass necessarily in respect to the vengeance upon the rowers of the impious men, that justice demanded their lives. And in proof of this judgment, Pantocles, the Lacedemonian, having set forth to go through Sparta to reach those absent from the force with Dionysus who were in Cythera, when he had seated himself on the bench of the Ephors, was torn to pieces by dogs."

3. *Pausanias, Description of Greece, Book VII., Caps. XXIV.–XXV.*—It is well known that this famous traveler lived in the time of the Antonines, and probably finished his work in the reign of the Emperor Marcus Aurelius, about 170 A. D. A very excellent translation with critical introduction and copious commentary, the whole in six volumes, has recently been published by J. G. Frazer, M.A., LL.D. (Glasgow), fellow of Trinity College, Cambridge (MacMillan & Co., London, 1898). The following accounts of the destruction of Helike and Bura are taken from Frazer's translation.

In the description of Achaia, Book VII., Chap XXIV. (pp. 365–366) Pausanias says:

"Going on you come to the river Selinus, and forty furlongs from Ægium is a place Helice on the coast. Here there used to be a city Helice, and here the Ionians had a most holy sanctuary of Heliconian Poseidon. Their reverence for that god has survived to the present day, in spite of their expulsion by the Achæans and their migration first to Athens, and afterwards to the coast of Asia. At Miletus, on the way to the spring of Biblis, there too is an altar of Heliconian Zeus in front of the city; and in Teos, too, the Heliconian god has an enclosure and an altar which are worth seeing. Homer also refers to Helice and Heliconian Poseidon. 5. But in after time the Achæans of Helice forced some suppliants from the sanctuary, and put them to death. The wrath of Poseidon did not tarry. The land was instantly visited by an earthquake, which swallowed up not only the buildings, but the very ground on which the city had stood. Ominous signs, vouchsafed by the god, foretell the approach of great and far-reach-

:es. The nature of the sign is generally the same. For earth- 'eceded either by heavy and continuous rains or long droughts. too, is unseasonable. If it is winter, the weather is sultry; if it iere is haze, and the sun's disc appears of an unusual colour, iing either to red or dun. Springs of water mostly dry up. sometimes sweep across the country, blowing the trees down. too, the sky is shot with sheets of flame. Stars are seen of an 'er before known, and strike consternation into beholders. More- ty murmur is heard of winds blowing underground. And many there are whereby the god gives warning of the approach of earthquakes. The character of the shock itself is not always the . The original observers and persons instructed by them have been to distinguish the following classes of earthquakes. The mildest form arthquake—if so dire a calamity can be thought to admit of alleviation—is when the first shock which levels the buildings with the ground, is counteracted by an opposite shock which raises up what the first had knocked down. In this kind of earthquake you may see columns, which had been all but hurled from their bases, rising to the perpendicular, and walls which had been cracked closing up again; and beams, which the shock had caused to slide out, return to their places, and similarly rifts made in conduits and water-channels are cemented better than they could have been by a craftsman. The second kind of earthquake destroys everything that is the least unsteady; whatever it strikes it instantly overthrows, as with the blow of a battering ram. The deadliest kind of an earthquake is illustrated by the following comparison. In an unintermitting fever a man's breathing is quick and laboured, as is shown by symptoms at various points of the body, but especially at the wrists; and they say that in the same way the earthquake dives under buildings and upheaves their foundations, just as molehills are pushed up from the bowels of the earth. It is this kind of shock alone that leaves not a trace of human habitation behind. They say that the earthquake at Helice was of this last kind, the kind that levels with the ground; and that, besides the earthquake, another disaster befell the doomed city in the winter-time. The sea advanced far over the land and submerged the whole of Helice, and in the grove of Poseidon the water was so deep that only the tops of trees were visible. So that between the suddenness of the earthquake and the simultaneous rush of the sea, the billows sucked down Helice and every soul in the place. 7. A like fate befell a city on Mount Sipylus; it disappeared into a chasm, and from the fissure in the mountain water gushed forth, and the chasm became a lake named Saloe. The ruins of the city could still be seen in the lake until the water of the torrent covered them up. The ruins of Helice are also visible, but not so clearly as before, for they have been eaten away by the brine."

Again in Chapter XXV. (p. 367) these additional remarks are added:

"The Lacedæmonians also slew men who had taken refuge in the sanctuary of Poseidon at Tænarum; and not long afterward their city was shaken by so prolonged and severe an earthquake, that not a house in Lacedæmon stood the shock.

"2. The destruction of Helice took place when Astius was archon at Athens, in the fourth year of the hundred and first Olympiad, in which Damon of Thurii was victorious for the first time. As none of the inhabitants survived, the territory now belongs to Ægium. . . .

"5. Returning from Cerynea to the high road, and proceeding a little way along it, we turn off a second time from the sea to the right in order to reach Bura. The town stands on a mountain. They gave it the name of a woman, Bura, whose father was Ion, son of Xuthus, and whose mother was Helice. When the god blotted out Helice from among men, Bura also was overtaken by a severe earthquake which spared not even the ancient images in the sanctuaries. Such people as chanced at the time to be away at the wars or on other business were the only survivors, and they rebuilt Bura. There is here a temple of Demeter, another of Aphrodite and Dionysus, and another of Illithyia. The images are of Pentelic marble, and are works of Eluclides, an Anthenian. The image of Demeter is clothed. There is also a sanctuary of Isis.

"Having descended from Bura in the direction of the sea, we come to a river named Buraicus and to a small image of Hercules in a grotto. This image is also surnamed Buraicus, and there is a mode of divination by means of dice and a tablet. The person who inquires of the god prays before the image, and after praying he takes four dice and throws them on the table. Each die has a certain figure marked on it, and the meaning of each figure is explained on the tablet.

"The straight road from Helice to the Hercules is about thirty furlongs. Going on from the Hercules you come to the mouth of a river which comes down from a mountain in Arcadia, and never dries up. The river is called the Crathis, and Crathis, too, is the name of the mountain which are its springs. From this Crathis the river beside Crotona in Italy got its name. On the bank of the Achæan Crathis once stood the city of Ægæ; they say that in course of time it was deserted by its inhabitants, because they were a feeble folk."

In his excellent and lucid commentary on Pausanias' "Description of Greece," Frazer says of *Bura:*

"Between the Bouphousia (Cerynites) and Kalavryta (Buraicus) rivers there rises a massive hill, which falls away on the south and west in a line of stupendous precipices. This is the hill or mountain of Bura; it is now called by the natives *Idra.* On the north the hill is separated from the sea by a strip of level coast land; on the southern side it is connected by a neck or saddle (which is, however, far below the summit of the hill) with the loftier mountains which begin here and stretch away into Arcadia. On this neck or saddle are the remains of Bura. They consist of extensive, though insignificant, remains of walls and foundations, spread along the southern part of the western foot of the hill as far as the copious spring which gushes from the bottom of the precipice. Among the ruins is a chapel of St. Constantine, which presumably occupies the site of an ancient sanctuary. Mixed with the ruins are huge blocks of rock which appear to have been hurled from the beetling crag above by an earthquake, perhaps the same earthquake which destroyed the city.

"The whole neighborhood gives one the impression that it has been subjected to gigantic convulsions of nature. The crags tower up to dizzy heights above the traveler, and the rivers find their way through tremendous gorges to the sea.

"At the southwestern foot of the hill of Bura, where the precipices rise highest, lie the ruins of the ancient theatre, with remains of fifteen rows of seats; the orchestra is about 32 paces broad. From some of the seats there is a fine view of the Corinthian Gulf, with the mountains of northern Greece rising behind it. A few remains of the town wall may be seen below the theatre.

"The citadel of Bura probably occupied the summit of the hill. The western face of the hill is a sheer wall of rock; a single path here leads to the summit."

From this account it is clear that most of the site of Bura is too high above the sea to have been inundated by the seismic sea wave of 373 B. C., and that the damage was due principally to the violent shocks during that dreadful earthquake. Pausanias says that it was so violent "that it spared not even the ancient images in the sanctuaries. Such of the people as chanced to be away at the war or on other business were the only survivors, and they rebuilt Bura." This accords well with descriptions of the yawning chasms at B[illegible] given by Aristotle, Lucretius and other writers.

It also appears that according to the authorities availabl[illegible] Pausanias, Helike subsided so much that only the tops of the [illegible]le[illegible] in the grove about the temple of Poseidon remained above the [illegible] tr[illegible] As this temple could not well have been less than fifty feet [illegible] wat[illegible] sea level, the total subsidence must have been about a hundr[illegible] abo[illegible] This effectively disposes once for all of the claims of P[illegible] ed fee[illegible] Suess and others that it was caused by the breaking loose of [illegible] rofessor from the older geological formations. It is therefore plac[illegible] alluvium doubt that under the throes of the earthquake the bed of [illegible] d beyond Corinth gave down and thus brought [illegible] famous [illegible]e Gulf of of antiquity. [illegible]inundation

There seems to have [illegible] that year (373 B. C.), but unfor[illegible] [illegible]tain to enable us to fix up[illegible] Pausanias says that "besid[illegible] the doomed city in the [illegible] all probability the sinki[illegible] the later shocks, as [illegible] agrees also with the

somewhat vague language of Diodorus Siculus, who says that the sea wave occurred in the day following the earthquake at night. None of these accounts are to be too implicitly trusted, because Pausanias says no one at Helike escaped, while Diodorus implies that some persons were escaping when the wave overwhelmed the city.

If there had been a series of slight but incessant earthquake shocks previous to the terrible earthquake at night, the account given by Ælianus of the exodus of mice, weasels, and other animals from the town becomes very intelligible; but here again we must beware of reposing too much confidence in narratives composed after the lapse of several centuries. Of all the contemporaries of this event, Aristotle was best qualified to speak with authority; but, as we have seen, his account gives only the leading facts without the details added by later writers, and is impossible to estimate how many of these details are authentic.

On the whole it appears to be certain that there were many premonitory signs of the disaster, in the form of a series of preliminary shocks extending through several months and felt all over the Peloponnesus; and it seems equally certain that the greatest shock occurred in the night. This leveled Helike and Bura to the ground, and was due to the expulsion from beneath the bed of the sea of a mass of lava which was pushed under the mountains in Arcadia, causing great chasms to open near Bura. In consequence of this undermining of the sea bottom it afterwards gave down nearly a hundred feet, but we cannot be sure whether the subsidence took place with the great shock in the night, or followed from one of the violent aftershocks the next day. On the whole the latter view seems the most probable, since there is no reason why the sea bottom once undermined might not sink with one of the violent after shocks which always follow great earthquakes.

When we consider the interval of time by which we are removed from this great disaster, it is quite remarkable that our knowledge of it should be so complete as it is. Plato was then in his fifty-fourth year, at the height of his powers, and at the head of the Academy in Athens, and Aristotle was a boy eleven years old; but the impression made upon contemporary Greek thought was proportionate

to what might have been expected from the sudden obliteration of Helike, at once the most important city in Achaia, and the center of the Panionian league, owing to the prosperity and increasing prestige it had enjoyed since the days of Homer. As Aristotle tries to account for the disaster by the theory of opposing winds, it is evident that it must have been a subject of keen speculation among the leading Greek philosophers. Although the explanation given by Aristotle is now invalidated by the advancement of science, he was entirely correct in ascribing this dreadful calamity to the agitation of vapors confined within the earth, which in seeking release finally brought on the cataclysm.

There are few results in science of deeper interest than those obtained by a principle which enables us to remount to the earliest ages of history, and to explain phenomena contemporaneously observed by the greatest minds of antiquity. This impressively illustrates the difference between a discovery disclosing a true physical cause and an effort directed to the mere observation of phenomena. A *vera causa* explains with equal facility the phenomena of every country and the observations of every age, whereas without it we can not correctly understand the commonest phenomena witnessed in our own time.

April 30, 1907.

Final Note.

Since the above discussion was completed, the writer has been much impressed with the excellent maps of the ocean depths published by the U. S. Coast and Geodetic Survey (Physical Hydrography, Manual of Tides, Part IV A, by Rollin A. Harris, Appendix 7, Report for 1900). The reader is requested to study especially maps 19 and 20, of this appendix, and to notice how the earthquake belts of the world as laid down by Milne follow the deep trenches in the sea. The borders of the North Pacific ocean, about Alaska, the Aleutian and Kurile Islands, and Japan are literally surrounded by these deep, narrow trenches, running right through the centres of the great earthquake belts of the globe. As these trenches are very long, narrow, and deep, and at the same time exactly paralleled by chains of islands rising out of the sea, which are mountain ranges under water, we see at once the true cause of earthquakes. The

expulsion of lava from under these trenches has raised the adjacent ridges, and when thus undermined the sea bottom has sunk down. This may be inferred with entire confidence and certainty not only from the relative situation of the trenches and adjacent ridges, but also from the great earthquakes and accompanying seismic sea waves observed in these regions within historical times. No other interpretation of the phenomena than the one we have given is really possible. If, however, any one should still cling to the old theory that the shrinkage of the earth is an effective cause in modifying the surface of our globe, let him explain why the shrinkage should take place in these long narrow trenches and be accompanied by the elevation of adjacent ridges. The elevation of the ridge shows that matter is pushed under it, and the sinking of the bed of the adjacent trench shows that the sea bottom is undermined. It therefore incontestably follows that lava is expelled from under the trench and pushed under the adjacent crust, upheaving it into the form of a ridge. Thus mountain ranges are formed in the sea and eventually raised above the water; and hence they run so exactly parallel to the shore. Earthquakes, volcanoes, mountain formation, formation of islands and plateaus, the feeble attraction of mountains, and great seismic sea waves,—six great classes of phenomena not heretofore closely associated,—are referred to one common cause, namely, the development of steam beneath the earth's crust, owing principally to the secular leakage of the ocean bottoms. The discovery and verification of this *vera causa* of the principal phenomena of the earth's surface ought to enable us to extend the domain of useful knowledge, and to give a better basis to many of the physical sciences.

Blue Ridge on Loutre,
Montgomery City, Missouri, July 2, 1907.

Stated Meeting May 3, 1907.

President SMITH in the Chair.

Dr. J. P. Crozer Griffith, Prof. John C. Rolfe and Dr. Allen J. Smith, newly elected members, were presented to the chair and took their seats in the Society.

Acknowledgments of election to membership and acceptances of the same were received from:

J. J. Jusserand, LL.D., Washington.
George Ferdinand Becker, Ph.D., Washington.
Charles Benedict Davenport, Ph.D., Cold Spring Harbor, L. I.
J. P. Crozer Griffith, M.D., Philadelphia.
Frank Austin Gooch, Ph.D., New Haven.
Herbert Spencer Jennings, Ph.D., Baltimore.
James Playfair McMurrich, Ann Arbor, Mich.
Edward Laurens Mark, Ph.D., LL.D., Cambridge, Mass.
John Bassett Moore, LL.D., New York.
Francis Eugene Nipher, St. Louis.
Horace Clark Richards, Ph.D., Philadelphia.
John C. Rolfe, Philadelphia.

A letter was received from the New York Academy of Sciences inviting the Society to be represented at its celebration of the two hundredth anniversary of the birth of Linnaeus on May 23d. The invitation was accepted and Dr. John W. Harshberger was appointed to represent the Society.

The following papers were read:

"The Proposed International Tribunal of Arbitration [illegible]," by THOMAS WILLING BALCH, Esq. (see page [illegible]) [illegible] discussed by Prof. Lewis M. Haupt.

"Greek Theories of Sound [illegible]" [illegible] ROMAINE NEWBOLD, Ph.D.

The President announ[illegible] delegates to the Sev[illegible] E. G. Conklin, Will[illegible]

Stated Meeting May 17,1907.

Mr. Horace C. Richards, a newly elected member, was presented the chair and took his seat in the Society.

Acknowledgments of election to membership and acceptances of same were received from:

George Carey Foster, F.R.S., D.Sc., LL.D., Rickmansworth, rts, England.

John C. Kepteyn, Groningen, Holland.

Sir William Turner, K.C.B., D.Sc., D.C.L., F.R.S.

The decease of the following members was announced:

Prof. Albert Henry Smyth, at Philadelphia, on May 4, 1907, æt. 44.

Prof. Albert Réville, of Paris.

Dr. J. G. Rosengarten read an obituary notice of the late Prof. bert H. Smyth.

The following papers were read:

"The Mating Habits of Dragon-Flies," by Dr. Philip P. Calvert.

"A Comparative Review of the East Indian Pitcher Plants or :penthes," by Prof. John M. Macfarlane.

"New Derivatives of Columbium," by Dr. Edgar F. Smith.

THE PROPOSED INTERNATIONAL TRIBUNAL OF ARBITRATION OF 1623.

By THOMAS WILLING BALCH.

(*Read May 3, 1907.*)

The approaching second Hague Peace Conference, at which it is proposed to discuss the possibilities of placing some limit on the expansion of armaments, calls public attention again to the evolution and development of one of the most beneficent of human institutions—international arbitration. The first glimmers of humanity seeking to avoid the horrors entailed by war are lost in the haze of early history. Probably we shall never know with whom the idea of international arbitration originated. One of the earliest written expressions of the wish to escape the arbitrament of arms was given by the prophet Micah, who was born about 750 B. C., when he said:

"And He shall judge among many people, and rebuke strong nations afar off; and they shall beat their swords into plow-shares, and their spears into pruning-hooks: nation shall not lift up a sword against nation, neither shall they learn war any more."

And a little later the prophet Isaiah said:

"And He shall judge among the nations, and shall rebuke many people: they shall beat their swords into plow-shares, and their spears into pruning-hooks: nation shall not lift up sword against nation, neither shall they learn war any more."

The Greeks made some attempts at arbitration among themselves, notably in an agreement between the Lacedaemonians and the Argives. But with the "barbarians" who formed the rest of the world, the Greeks, apparently, would not arbitrate. For a long time the Romans as the masters of the world maintained peace by force of arms but not by arbitration.

In the twelfth century Gerohus[1] or Gerloius is said to have suggested something like arbitration; and in the reign of Philippe le Bel of France (1285–1314), Pierre Dubois is believed to have out-

[1] "International Tribunals," by W. Evans Darby, London, 1904, p. 22.

lined a plan intended to maintain to some extent peace in Europe. He restricted this, however, to the Christian Powers: the so-called Infidels were to be outside of its pale. Indeed, those individuals who would not accept the decree of Dubois's proposed peace board were to be impressed into fighting the Infidels.

An early proposer of modern international arbitration was a Frenchman, Éméric Crucé. He is still almost unknown, except to a few international jurists. He was born at Paris about 1590 and died in 1648. He published a number of works in Latin, but so little is known about him that, until 1890, when Judge Ernest Nys,[1] Conseiller à la cour d'Appel of Brussels, a Belgian member of The Hague Permanent Tribunal of Arbitration, and a scholar of the highest type, restored to Éméric Crucé his true name, publicists called him Emery de la Croix. In 1618 Crucé printed an annotated copy of Statius. That publication gave rise to a violent contemporaneous discussion, which was the means through which Judge Nys discovered Crucé's real name.

"If we cite this polemic it is because," Judge Nys says, "it allows us to know the exact name of the author of ['Le Nouveau Cynée']. The few ancient authors who speak of him call him generally 'Emericus Crucejus or de La Croix'; modern biographers call him, 'Emeric de la Croix.' The fact is his name is Éméric Crucé, from which came the Latinized name of Crucaeus. Doubt is not possible, and we find a formal indication of this in the anagram that the 'Silvarum frondatio' contains, whose author was Antoine Dorcal, barrister of Paris. Here is the text:

"'Anagramma in Autorem Hujus Frondationis
Emericus Cruce
Ecce Mercurius.
Ne temere in Silvis Statianis lector oberres,
Ecce vialis adest hic tibi Mercurius."

"We can mention here that it was probably to the translator of the 'Bibliographia politica' of Gabriel Naudé that we owe the attribution to the author of 'Le Nouveau Cynée' of the name of de La Croix. Naudé writes correctly Emericus Crucaeus; the translator, Charles Challine, gives Emery de la Croix.

"The edition of the works of Statius is dedicated to Henri Godfroy; the notes on the Thebaïd of the same poet are dedicated to Guillaume Ribier, councillor of State, president and lieutenant-general at Blois; finally, the 'Silvarum frondation' is preceded by a letter addressed to Henri Le Clerc

[1] "La Revue de Droit International et de Législation Comparée," Brussels, 1890.

du Tremblay, councillor of the *parlement* of Paris, a brother of the councillor of Cardinal de Richelieu, François Le Clere du Tremblay, known to history by his religious name of Father Joseph."[1]

The work which should sooner or later make Émeric Crucé famous and in which he proposed an International Court of Arbitration between nations, he published at Paris in 1623, "Avec Privilège du Roy." It was entitled: "Le Nouveau Cynée ou Discours d'Estat."

This book is small, but it is filled with much reasoning. In the preface Crucé says: "This book would gladly make the tour of the inhabited world, so as to be seen by all the Kings, and it would not fear any disgrace, having truth for its escort, and the merit of the subject which must serve as letters of recommendation and credence."

Émeric Crucé held, especially for the times in which he lived, broad and liberal views. He believed that it was for the advantage of humanity that the different races and nations should not seek to injure and destroy one another by war, but rather to exchange their varied products. While he could not see as clearly as it is possible to-day that international trade is the power behind the throne of international peace, yet he realized that the development of international commerce would tend, by making countries more interdependent, to cause wars to grow less frequent. In this he agreed with the view expressed by Washington in a letter which the greatest of our Presidents wrote to la Fayette. Crucé favored the development of canals as a means of communication, an item of national policy that the Western nations of Europe have now largely adopted and one which the growing needs of cheap and easy communication is bringing more prominently before public opinion here. He was also an ardent supporter of religious toleration.

Crucé believed that general peace is possible. But he saw and proclaimed with a clear vision that as a prerequisite to the peaceful settlement of international disputes, some sort of machinery to dispose of international disputes was necessary. With this in view, he proposed "to choose a city where all sovereigns should have

[1] "Etudes de Droit International et de Droit Politique," by Ernest Nys, Brussels, 1896, p. 308.

perpetually their ambassadors, in order that the differences that might arise should be settled by the judgment of the whole assembly. The ambassadors of those who would be interested would plead there the grievances of their masters and the other deputies would judge them without prejudice. . . . That if any one rebelled against the decree of so notable a company, he would receive the disgrace of all other princes, who would find means to bring him to reason. The most commodious place for such an assembly is the territory of Venice, because it is practically neutral and indifferent to all Princes: added thereto that it is near the most important monarchies of the earth."

Crucé contemplated a universal union that should include even Persia, China, Ethiopia, the East Indies, the West Indies, indeed all the world. A delicate question was how to arrange the order of rank and precedence. He suggested as a possible solution of this difficulty the following order and some of the reasons for it:

First: The Pope, in part out of respect for ancient Rome.

Second: The Sultan of the Turks, because of "the majesty, power and happiness of his Empire," and also on account of the memory of the ancient Eastern Empire, of which Constantinople was the capital.

Third: The Christian Emperor.

Fourth: The King of France.

Fifth: The King of Spain.

The claims of the Kings of Persia and China, Prester John, the Precop (*sic*) of Tatary, and the Grand Duke of Moscow, must be arranged. Next the importance and order of precedence of the Kings of Great Britain, Poland, Denmark, Sweden, the Monarchs of Japan and Morocco, the Great Mogul and the other sovereigns demanded attention. Among other expedients, Crucé proposed to give the first place to the first comer, or to the oldest, or again *à tour de rôle.*

He was not blind to the fact that without the initiative of some one a nearer approach to international peace could never become a reality. In his opinion two potentates, the Pope and the King of France, could broach the subject to the sovereigns of the world, the former to the Christian princes, the latter to the Mohammedan

rulers. "Only let them publish peace by the order of the King!" Crucé wrote. "Those words will make them drop their arms from their hands."

Here again we find that history has repeated itself. In 1623 Éméric Crucé wanted the King of France to move in favor of universal peace. In 1898 it was the Emperor of Russia that called upon the Powers to send representatives to the Peace Conference that met the next year at The Hague. And while it was almost three centuries before the International Court that Crucé proposed became an actual fact, and two great wars have been fought since the Emperor Nicholas called the first Hague Conference together, yet—owing to the institution *ad hoc* before 1899 of International Courts of Arbitration to meet certain cases, such as those of the Alabama Claims and the Bering Sea Fur Seal Fisheries, and since 1899 by the establishment of the Permanent Hague Tribunal—some wars at least have been avoided.

The *Grand Dessein* attributed to Henry of Navarre, but very likely a product of the Duc de Sully's imagination, is often cited as the first serious project of international arbitration. Sully's Memoirs, which give us everything we know about the *Grand Dessein*, were not published until 1638, or fifteen years after Éméric Crucé had given to the world his plan for the establishment of an International Court at Venice. But in addition, whether the *Grand Dessein* was an actual historic fact or not, that plan, attributed by the Duc de Sully to his sovereign, Henry the Fourth, was not drawn so as to settle the differences of the European nations by means of arbitration, but to overthrow as the dominating power of Europe the House of Hapsburg by means of a league of the other European states, at the head of which would be the King of France. The basic thought of the *Grand Dessein* was not peace but armed force its purpose was well expressed by the lines of Wordsworth in "Rob Roy's Grave":

> "The good old rule
> Sufficeth them, the simple plan,
> That they should take who have the power,
> And they should keep who can."

The proposal of Éméric Crucé for an International Court bore good fruit. Gabriel Naudé in his "Bibliographia Politica" (1642)

mentions Le Nouveau Cynée, "done rather for recreation of the mind," he says, "than on account of any opinion that the writer had that the advice that he gives can ever succeed." Again, in 1664, Charles Sorel writes: "There is a book called 'Le Nouveau Cynée,' which gives reasons for the establishment of a general peace and freedom of trade through all the world. One imagines that something additional is necessary to make it a success, but the design is always beautiful and bold." Later still, Leibniz, in a letter that he wrote to l'Abbé Castel de Saint Pierre concerning the latter's "Paix perpétuelle," said apropos of Crucé's work: "When I was very young I knew a work entitled 'Le Nouveau Cynée,' whose unknown author counselled sovereigns to rule their states in peace and to submit their differences to an established tribunal; but I do not know how to find this book and I do not remember now any details. It is known that Cineas was a confidant of King Pyrrhus who advised the latter to rest himself at first, as it was his object, as he confessed it, when he had conquered Sicily, Rome and Carthage."

That mankind was eager to mitigate the horrors of war, and in some measure at least to save itself from the miseries entailed by endless war, was proved by the rapid and complete success of the *magnum opus*, "De Jure Belli ac Pacis," of Hugo Grotius. That monumental book, on the "Laws of War and Peace," Grotius gave to the world in 1625, two years after Émeric Crucé published "Le Nouveau Cynée." Grotius wrote with the view of softening the unspeakably horrible usages of war. That great Captain of the Thirty Years' War, Gustavus Adolphus, carried a copy with him in his campaigns and acted upon many of its principles. And in the peace of Westphalia, in 1648, the leading principles formulated by Grotius were recognized. Grotius lived for a time in Paris, and probably knew Crucé and his work, and possibly gained some of his ideas on international arbitration from the Frenchman's book.

Other men wrote in favor of trying to avoid war. The founder of our own Commonwealth, William Penn, published in 1693 an "Essay toward the Present and Future Peace of Europe." He referred with approval to the Grand Dessein of Henry of Navarre, and argued that as England had her Parliament and France her States General to settle their respective affairs, so all Europe should

ts Parliament to arrange international disputes. Then Castel 're, Jeremy Bentham, Emanuel Kant and others wrote ı international peace. The great thinker and doer, who .. :nis venerable society, also believed in international arbitra- In *The Writings of Benjamin Franklin* by our fellow mem-)fessor Smyth, there is a letter of Franklin to Mrs. Mary ..on, dated at Passy, in January, 1783, in which he says *inter* "At length we are in Peace, God be praised, and long, very , may it continue. All Wars are Follies, very expensive, and v nischievous ones. When will Mankind be convinced of this, anu agree to settle their differences by Arbitration?" And further there is his famous saying on the merits of peace and war, "There never was a good war, nor a bad peace." Since the beginning of the nineteenth century many jurists and publicists have advocated the adoption wherever it was possible of international arbitration: William Ladd, Charles Sumner, Richard Cobden, Thomas Balch, Francis Lieber, James Lorimer, David Dudley Field, Emile Baron De Laveleye, Ivan de Block, Philip Stanhope, Baron Descamps, the

[1] This paper was read before the Society on May 3, 1907: Professor Smyth died the next day, and so the following letter that he wrote only eight days before is not without interest for the members of the Philosophical Society.

THE ART CLUB
OF PHILADELPHIA

April 26th, 1907

My dear Mr. Balch

Franklin says in a letter to Mrs. Mary Hewson (Vol. IX., p. 12, of my edition), "At length we are in Peace, God be praised, and long, very long, may it continue. All Wars are Follies, very expensive and very mischievous ones. When will Mankind be convinced of this, and agree to settle their Differences by Arbitration? Were they to do it, even by the Cast of a Dye, it would be better than Fighting and destroying each other." I would call your attention particularly to Franklin's "Propositions relative to Privateering," communicated to Mr. Oswald (Vol. IX., pp. 4-7). I think you will find quotable matter there. See also letter to David Hartley (Vol. X., p. 72), "God grant that not only the Love of Liberty, but a thorough knowledge of the Rights of Man, may pervade all Nations of the Earth so that a Philosopher may set his Foot anywhere on its Surface, and say, 'This is my Country.'"

Remember Franklin's oft repeated assertion, "There never was a good War or a Bad Peace."

Faithfully yours,

ALBERT H. SMYTH.

Emperor Nicholas the Second, and our own members, Ex-President Cleveland, Andrew Carnegie and the Baron d'Estournelles de Constant. The latter, together with our late fellow countrymen, Frederick W. Holls, a Pennsylvanian by birth, played an important part at the first Hague Peace Conference in 1899 in securing the establishment of The Hague International Tribunal,[1] and is to be one of the chief delegates of France at the second Hague Peace Conference next month.

The past development of international arbitration gives promise for its future usefulness, although grave difficulties are certain to arise in its application. Cases involving rather private than national interests can be solved by arbitration. To this class of cases belonged the Alabama Claims and the Bering Sea Seal Fisheries, and the Dogger Bank Incident. Those disputes were not of such a nature that one of the disputants must give way in order that the progress of the other should not be impeded, as was the case in 1870 between France and Prussia. Neither were those cases legacies growing out of bloody and bitter wars between the contestants. In all three of those cases the litigants were anxious if possible to avoid war, and a resort to Courts of Arbitration, in the first two cases appointed *ad hoc*, in the latter to The Hague Tribunal, enabled them to avoid war honorably. These three cases are concrete proof that international arbitration is possible in some cases. As Mr. Thomas Balch of the Philadelphia Bar wrote in 1874 in "International Courts of Arbitration"[2] apropos of the Alabama Claims: "The friends of International Courts may fairly assert that this mode of settling great national questions has been fully and successfully tried, that it may be considered as having thereby passed into and henceforth forming a distinct part of that uncertain and shapeless mass of decisions and dicta which we call International Law. Without participating in the visions so grandly developed by Zuinglius, and so fondly cherished by Grotius, of the good time, a good time to be won only by toil and unremitting effort—

"Till the war-drums throbb'd no longer, and the battle-flags were furl'd
In the Parliament of man, the Federation of the world."

[1] "The Peace Conference at the Hague," by Frederick W. Holls, New York, 1900.

[2] "International Courts of Arbitration," by Thomas Balch, 1874, reprinted at Philadelphia, 1899, p. 23.

we may reasonably expect that through such tribunals, through their proceedings and decisions, and not through empirical codes, we may ultimately arrive at some more tangible and better ordered system of International Law; one to which the assent of civilized peoples may be given greatly to the benefit and peace of mankind."

In this series of cases the disputing nations thought that the questions at issue were not of sufficient importance to make it worth their while to dislocate all their national wealth and prosperity in resorting to the drastic and uncertain arbitrament of war. But in an international quarrel over the possession of vast territory, such as the war between Russia and Japan for the control of Northern China, different interests much more difficult to deal with are involved. In that case the bone of contention seemed to both sides so rich and also so fundamental to their national interests that neither would agree to give way in the least particle, and war had to result.

The many international questions submitted to arbitration since the United States and England agreed to arbitrate the Saint Croix River boundary in 1794 prove that some international difficulties can be arranged by peaceful means, and that Éméric Crucé was not altogether visionary in his ideas. Though the changes wrought in recent years by force of arms in the affairs of the world prove that war has lost little of its influence upon human affairs and that it remains the last resort in settling international quarrels, yet the Alabama Claims, the Bering Sea Fur Seal Fisheries, and the cases that have been settled by The Hague Tribunal since it was established, give hope and encouragement for the future peace of the world.

In the evolution of international peace Éméric Crucé played an important part; he deserves to be much better known than he is; and his name should be given a high place among those of the men who have helped to settle, in some measure, international disputes by judicial instead of martial means. For in the early part of the seventeenth century Éméric Crucé's proposal for setting up at Venice an International Court to judge between the sovereigns of the world was a rough sketch of The Hague Permanent Tribunal instituted in 1899. Probably, not until long after 1623, did any *irenist,* to use the happy word coined by the Abbé de Saint Pierre

to designate a worker for international peace, suggest a plan as practical for promoting the advent of international peace as that put forward by the obscure and all but forgotten Parisian scholar.

The world is apt to give fame to the military destroyer or the government official and not to the scholar or the scientific discoverer. In these latter days, when some note is taken of the men who have sought to evolve a human institution that should at least lessen the frequency of wars, with the ultimate aim perhaps of abolishing them altogether, credit is usually given to those who hold government positions, while the share of the scholar is as apt to be forgotten as the work of the skilled workman who turns the precious, uncut stone into the brilliant gem. This has happened, for instance, in the case of the Alabama Arbitration. And among the savants and original thinkers who have not received their just due in advancing the peace of the world is Émeric Crucé, who is one of the forebearers of The Hague International Tribunal of Arbitration.

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OF THE

AMERICAN PHILOSOPHICAL SOCIETY

HELD AT PHILADELPHIA

FOR PROMOTING USEFUL KNOWLEDGE

VOL. XLVI. OCTOBER–DECEMBER, 1907. NO. 187.

CONTENTS.

PHILADELPHIA
THE AMERICAN PHILOSOPHICAL SOCIETY
104 SOUTH FIFTH STREET
1907

American Philosophical Society

General Meeting—April 23-25, 1908

The General Meeting of 1908 will be held on April 23d to 25th, beginning at 2 p. m. on Thursday, April 23d.

Members desiring to present papers, either for themselves or others, are requested to send to the Secretaries, at as early a date as practicable, and not later than March 25, 1908, the titles of these papers, so that they may be announced on the programme which will be issued immediately thereafter, and which will give in detail the arrangements for the meeting.

Papers in any department of science come within the scope of the Society, which, as its name indicates, embraces the whole field of useful knowledge.

The Publication Committee, under the rules of the Society, will arrange for the immediate publication of the papers presented.

I. MINIS HAYS
ARTHUR W. GOODSPEED
JAMES W. HOLLAND
AMOS P. BROWN

Secretaries.

Members who have not as yet sent their photographs to the Society will confer a favor by so doing; cabinet size preferred.

It is requested that all correspondence be addressed

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TAXONOMIC CHARTS OF THE MONOCOTYLEDONS AND THE DICOTYLEDONS.

BY JOHN W. HARSHBERGER, PH.D.

(*Read April 19, 1907.*)

At various times botanists have constructed phylogenetic diagrams to show the evolutionary relationship of the various families of plants, but in all of these family trees the attempt has been made to represent the actual evolutionary history of each plant group. Beyond representing the general lines of evolution of the vegetable kingdom, these diagrams, it seems to the writer, do not go. Haeckel in his "Phylogenie der Protisten und Pflanzen" gives elaborate tables to represent the phylogeny of different plant groups, Campbell in his lectures on the "Evolution of Plants" (1899) gives at the close of each important section of his book family trees of the algæ, fungi, mosses, ferns and flowering plants. Bessey[1] in 1897 discussed before the Botanical Society of America the phylogeny and taxonomy of the angiosperms, while Engler in *The Botanical Gazette* in May, 1898 (pp. 338–352), discusses the taxonomic division of the spermatophytes, as an abridged treatment of the same subject in Parts II., III. and IV. of the supplement to his "Die natürlichen Pflanzenfamilien." Bonnier and Sablon give useful

[1] Bessey, Charles E., "The Phylogeny and Taxonomy of Angiosperms," *Botanical Gazette*, XXIV (1897).

omic relationships in their large text-book of botany ›tanique Phanerogames").

n this same field of botanical speculation and inves- lber of important papers have appeared which ap- s ect from the morphologic and histologic sides. Cur- ms "Text-Book of General Botany" (1897) conjectures the e of the affinities of monocotyledons and dicotyledons, stating t the monocotyledons may be considered as a branch that has d ed from the dicot s type and become structurally owing to their aqua . He also gives a short statement of the evolution of the and of floral types. One of the interesting theories regarding the evolution of the higher g plants is one proposed by Balfour[1] on the philosophy of nd vegetation. In this paper, Balfour traces the evolution pes which being exposed to the failure of water show con- l difficult movement of the sperm cells and, therefore, have themselves gradually to a dry environment by the development of flowers and true seeds. Campbell[2] describes the causes that led to the general abandonment of the aquatic habit and the adoption of a land habit, which characterizes the predominant plants of the present time. The adoption of the seed habit, according to Scott,[3] gives the plant possessing such a habit the following advantages:

1. Pollination on the parent plant, and consequently greater certainty in bringing together the two kinds of spores.

2. Fertilization either on the plant or at least within the sporangium giving greater certainty of success and protection at the critical moment.

3. Protection of the young prothallus from external dangers.

Rendle in the *New Phytologist* (II:66, 1903) considers the origin of the perianth in seed plants, and later in 1904 in his book the "Classification of Flowering Plants" traces the affinities of the

[1] Balfour, Prof. I. Bayley, "Philosophy of Water and Vegetation, *Nature*, 64: 557, October 3, 1901.

[2] Campbell, D. H., "The Origin of Terrestrial Plants," *Science*, n. s., XVII: 93, 1903.

[3] Scott, D. H., "Origin of the Seed Habit," *Nature*, 68: 377–382, 1903.

gymnosperms and the monocotyledons in a clear and lucid manner. Ethel Sargant[1] from detailed macroscopic and microscopic studies of a large number of seeds and seedlings describes the dicotyledonous seedlings that show a well-marked cotyledonary tube, thus suggesting the origin of monocotyledons from a dicotyledonous stock. She gives a complete bibliography of the more important articles that have recently appeared on the subject, mentioning the work of Lyon on the embryogeny of *Nelumbo* and Holm on *Podophyllum peltatum* and *Erigenia bulbosa.* Harris[2] in a short article gives a brief, but useful, resumé of the attitude of modern botanists on the origin of monocotyledons from dicotyledons. Coulter and Chamberlain believe that the phylogeny of the angiosperms will always remain a baffling problem. They believe that there is not sufficient evidence of the monophyletic origin of monocotyledons and dicotyledons as claimed by Jeffrey, Queva, Sargant and others. They believe that the facts are strongly in favor of an independent origin of both monocotyledons and dicotyledons.

Having briefly reviewed the current theories concerning the origin and taxonomy of the angiosperms, it falls to the lot of the writer to describe the taxonomic charts which accompany this account. In the arrangement of the dicotyledonous and the monocotyledonous families, the plan has been adopted of showing the generally recognized affinities of the different groups, rather than absolutely relying on the proven natural descent, or evolutionary relationship. Wherever that descent has been established definitely by botanical investigation, it has been incorporated in the accompanying charts. Absolute affinity is an extremely difficult matter to determine in families of such widely diversified structure. It is important, however, to have some phylogenetic scheme which will picture in a diagrammatic way the supposed relationship of the numerous plant families. Such diagrams, the author believes, will greatly assist in the future investigation of the morphology, embryology and phylogeny of the flowering plants.

[1] Sargant, Ethel, "Theory of the Origin of Monocotyledons founded on the Structure of their Seedlings," *Annals of Botany*, XVII: 1–92, Jan., 1903.

[2] Harris, J. Arthur, "Monocotyledons or Dicotyledons," *The Plant World*, VI: 79, Apr., 1903.

In the preparation of the two original charts illustrating the taxonomy of the monocotyledons and dicotyledons, the author has been greatly assisted by Engler and Prantl's "Die natürlichen Pflanzenfamilien," Englers' "Syllabus der Pflanzenfamilien"

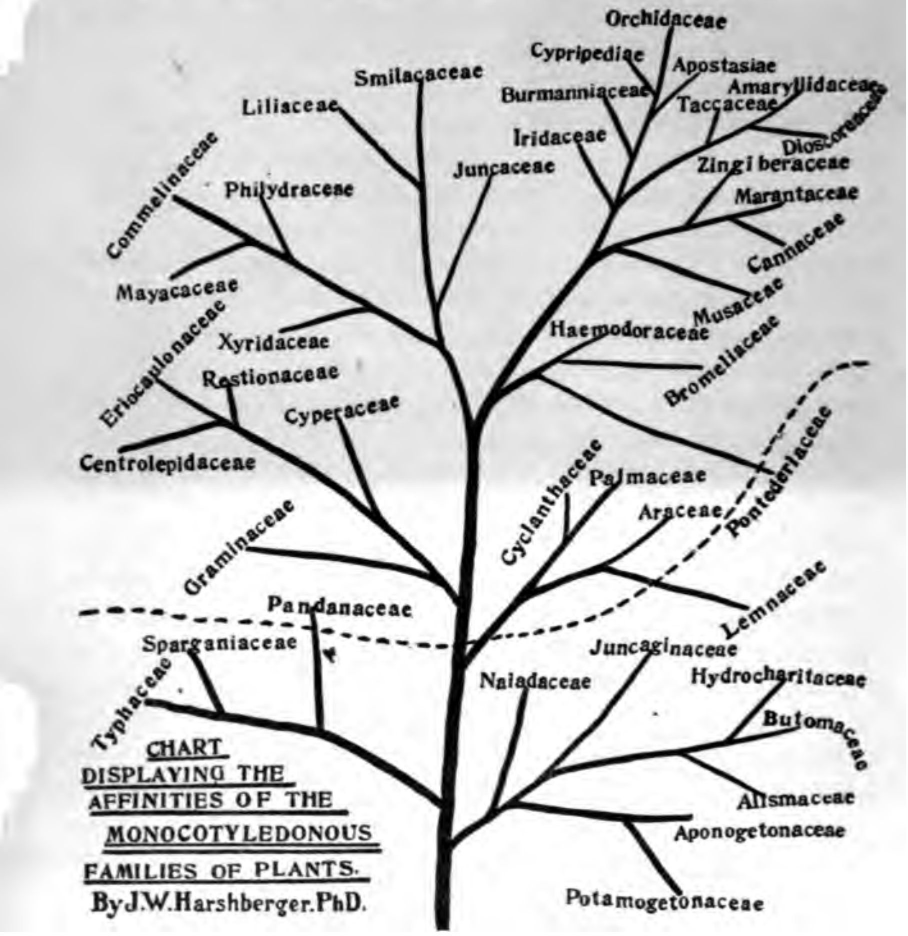

FIG. 1.

(1898), Warming's "Systematic Botany," Le Maout and Decaisne's "General System of Botany" (Mrs. Hooker's translation), Lindley's "Vegetable Kingdom" and Rendle's "Classification of Flowering Plants" (Volume I.).

Referring to the chart illustrating the taxonomy of the monocotyledons, the families may be divided roughly into two groups, the aquatic and terrestrial. Such aquatic orders as Naiadaceæ, Typhaceæ, Sparganiaceæ, Potamogetonaceæ and Aponogetonaceæ are according to the views of the writer undoubtedly primitive. The remarkable male flower of *Naias* in having a terminal stamen, which has either four longitudinal loculi, or one central one, and the female flower with unilocular gynœcium and single erect ovule with pollination under water are no doubt primitive characters. The Butomaceæ and Alismaceæ, as families of the order Helobiales, relate themselves according to some authors with some of the Ranales. And if the Ranales are not highly evolved in structure, having apopetaly and apocarpy, then the Helobic families are comparatively simple for the same reasons.

The families in which the parts of the flowers are surrounded by chaffy scales, namely the Cyperaceæ and the Graminaceæ, are probably not as closely related as was formerly supposed. Some botanists consider that the grass family is to be ranked as a primitive order and not a degraded liliaceous type through the Juncaceæ. This view the author believes is the correct one, and he has, therefore, removed the Juncaceæ from nearness to the Cyperaceæ and placed it as a more primitive form of Liliales with dry, scarious perianth segments. The families with petaloid perianth segments the author has placed on two separate limbs of the family tree. On one limb will be found the families in which the ovary is superior and on the other those families in which the ovary is inferior. Smilaceæ represent the most modified liliaceous type and Juncaceæ the least modified. The Bromeliaceæ, Marantaceæ, Amaryllidaceæ, Orchidaceæ and Iridaceæ, include the most modified types of plants with inferior ovary and are indicated by as many distinct branches of the family tree. Thus from Burmanniaceæ one proceeds to the Orchidaceæ through Apostasiæ and Cypripediæ. The family Dioscoreaceæ includes plants the flowers of which are dioecious forms of amaryllidaceous flowers. Beginning with Musaceæ the series passes through Zingiberaceæ and Cannaceæ to the Marantaceæ, and the botanist finds a strongly marked parallelism of development, the most marked tendency being the petaloid development of the sta-

mens and the style with the reduction of the number of fertile stamens to one.

The Palmaceæ and Araceæ stand off probably, as having affinities with each other, but not closely related to the other petaloideous, monocotyledonous families. Lemnaceæ may be considered to be a modified or degraded form of Araceæ, while the bromeliaceous plants with superior and inferior ovaries show affinities to the Amaryllidaceæ and the Liliaceæ, and hence, the writer has placed the order Bromeliaceæ on a branch near where the two upper limbs of the family tree diverge from each other. The complete liliaceous structure without great reductions in the number of whorls, but with generally few ovules in each loculus of the ovary, is found in the Commelinaceæ, while the Mayacaceæ, as a family, is closely allied to the Commelinaceæ. The Xyridaceæ are marsh plants with radical leaves arranged in two rows and short spikes on long stalks. The flowers, as in Commelinaceæ, have sepals (which, however, are more chaffy) the petals, but the outer series of stamens is wanting. The order Eriocaulonaceæ on another branch is sometimes called the "Compositæ among Monocotyledons" with radical and grass-like leaves, while the habit of the plants of the Restionaceæ is quite similar to the Cyperaceæ.

It is a much more difficult task to trace the affinities of the dicotyledonous families of plants. Roughly we may divide the families into the Incompletæ, the Apopetalæ and the Gamopetalæ. The plants of the primitive Incompletæ are all or nearly all of them provided with flowers that are wind pollinated. Such orders as the Salicaceæ, Myricaceæ, Juglandaceæ, Fagaceæ, Betulaceæ and Corylaceæ are not only wind pollinated, but the staminate flowers are in catkins, thus being advantageously situated for the discharged pollen to be carried away by the wind. The perianth in these orders is absent, or extremely rudimentary. The affinities of these primitive dicotyledons, as the writer has been enabled to determine them, is displayed in the larger of the two accompanying charts.

The apopetalous families in which the petals are absent or distinct are to be regarded as more primitive than the gamopetalous families. The relationship between the families is a group relationship. Thus the Loranthaceæ, Rafflesiaceæ, Balanophoraceæ, Santa-

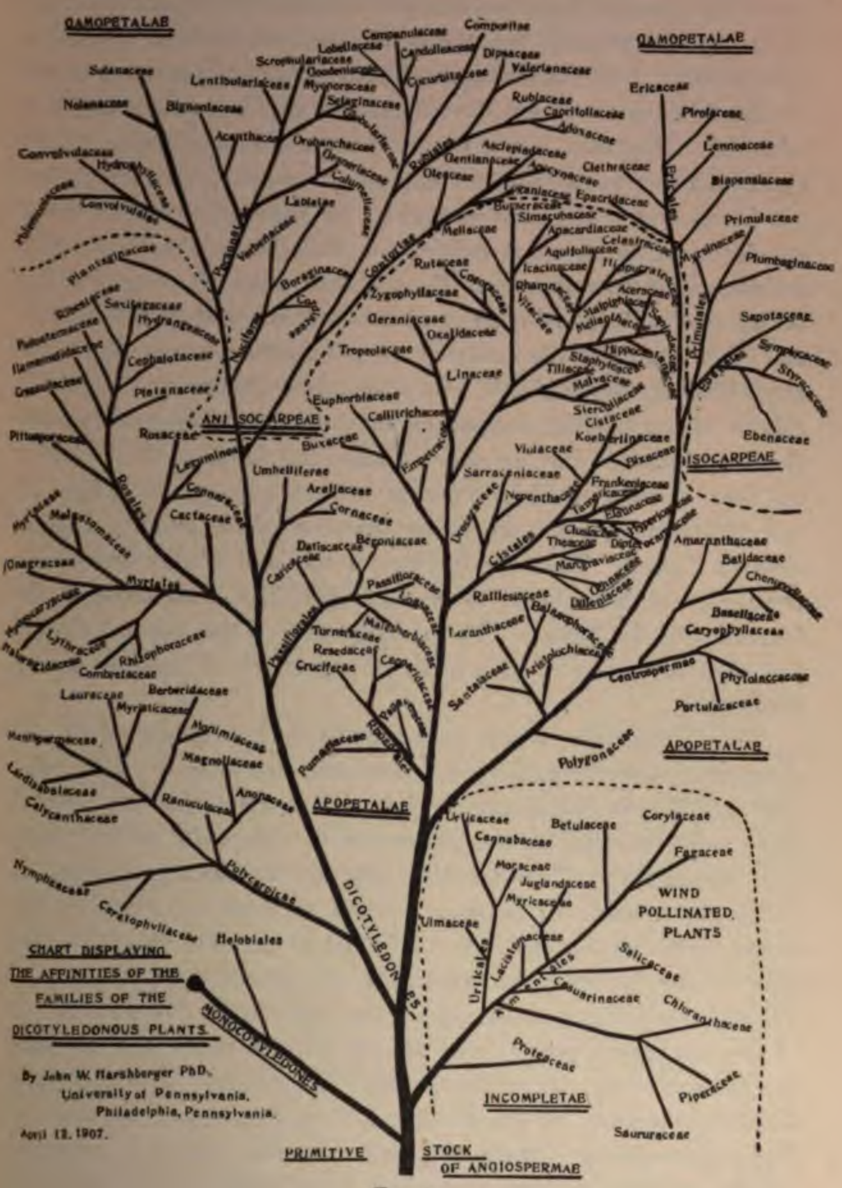
GAMOPETALAE
Campanulaceae
Compositae
Lobeliaceae
Scrophulariaceae
Solanaceae
Lentibulariaceae
Dipsaceae
Valerianaceae
Nolanaceae
Bignoniaceae
Selaginaceae
Rubiaceae
Caprifoliaceae
Adoxaceae
Acanthaceae
Orobanchaceae
Asclepiadaceae
Gentianaceae
Oleaceae
Convolvulaceae
Convolvulales
Labiatae
Verbenaceae
Boraginaceae
Plantaginaceae
Saxifragaceae
Hydrangeaceae
Cephalotaceae
Platanaceae
Pittosporaceae
Rosaceae
Rosales
Leguminosae
Connaraceae
Cactaceae
Melastomaceae
Onagraceae
Myrtales
Lythraceae
Rhizophoraceae
Combretaceae
Lauraceae
Berberidaceae
Myristicaceae
Monimiaceae
Magnoliaceae
Calycanthaceae
Ranunculaceae
Anonaceae
Nymphaeaceae
Polycarpicae
Ceratophyllaceae
Helobiales
CHART DISPLAYING
THE AFFINITIES OF THE
FAMILIES OF THE
DICOTYLEDONOUS PLANTS.
By John W. Harshberger PhD.
University of Pennsylvania.
Philadelphia, Pennsylvania.
April 12, 1907.
MONOCOTYLEDONES
DICOTYLEDONES
PRIMITIVE
STOCK
OF ANGIOSPERMAE
ANISOCARPEAE
Euphorbiaceae
Callitrichaceae
Buxaceae
Umbelliferae
Araliaceae
Cornaceae
Datiscaceae
Begoniaceae
Caricaceae
Passifloraceae
Passiflorales
Turneraceae
Malesherbiaceae
Resedaceae
Cruciferae
Capparidaceae
Papaveraceae
Rhoeadales
Fumariaceae
APOPETALAE
Contortae
Rutaceae
Zygophyllaceae
Geraniaceae
Oxalidaceae
Tropeolaceae
Linaceae
Meliaceae
Burseraceae
Simarubaceae
Anacardiaceae
Celastraceae
Aquifoliaceae
Icacinaceae
Rhamnaceae
Vitaceae
Aceraceae
Malpighiaceae
Tiliaceae
Malvaceae
Sterculiaceae
Cistaceae
Violaceae
Sarraceniaceae
Nepenthaceae
Droseraceae
Frankeniaceae
Tamaricaceae
Cistales
Theaceae
Dipterocarpaceae
Marcgraviaceae
Ochnaceae
Dilleniaceae
Rafflesiaceae
Balanophoraceae
Loranthaceae
Santalaceae
Aristolochiaceae
Polygonaceae
Centrospermae
Amaranthaceae
Chenopodiaceae
Basellaceae
Caryophyllaceae
Phytolaccaceae
Portulacaceae
APOPETALAE
GAMOPETALAE
Ericaceae
Pirolaceae
Lennoaceae
Clethraceae
Diapensiaceae
Epacridaceae
Ericales
Primulaceae
Myrsinaceae
Plumbaginaceae
Primulales
Sapotaceae
Symplocaceae
Styracaceae
Ebenales
Ebenaceae
ISOCARPEAE
Urticaceae
Cannabaceae
Moraceae
Ulmaceae
Urticales
Betulaceae
Corylaceae
Fagaceae
Juglandaceae
Myricaceae
Lacistemaceae
WIND
POLLINATED
PLANTS
Salicaceae
Casuarinaceae
Chloranthaceae
Proteaceae
Piperaceae
Saururaceae
INCOMPLETAE

FIG. 2.

:eæ are grouped together not only because of certain str
char: s, but because the plants of these orders show a p:
habit (ife. The Portulacaceæ, Phytolaccaceæ, Batidaceæ,
aceæ, Amaranthaceæ, Chenopodiaceæ and Basellaceæ fo
r ural group, while the Cornaceæ, the Araliaceæ a
:ræ form still another important branch of the dicot
y tree. The families that by the agreement of most
rm the order of Rhœdales are Resedaceæ, Cruciferæ
ıidaceæ, Papaveraceæ and Fumariaceæ, while the famili
ıg to the Ranal Alliance, and are thus suggestive of the
iance among monocotyledons, are Ranunculaceæ, Anc
ıoliaceæ, Berberidaceæ, Calycanthaceæ, Lauraceæ, etc
y of the families comprising the order, or alliance, Ro:
:ry strong. For the other groups and families, the en
en to associate them together in such a manner that tl
ɔranching will suggest the character of the affinity, w
distant. Thus the families at the base of any brar
d in the scheme to be more primitive than those
of the branch. The arrangement of the lateral bı
and their proximity to each other is suggestive of close or
relationship.

The Gamopetalæ, which are undoubtedly the highest of t
giosperms, naturally group themselves into two main trunks,
both a different phylogenetic origin. The writer has repre
these main branches, at the suggestion of Campbell,[1] as Iso
and Anisocarpeæ. The families included as Isocarpeæ sh
ovary that consists of as many carpels as there are petals
flower, and such families are considered to be more primitiv
those of the Anisocarpeæ, where the syncarpous ovary cons
a less number of carpels than there are petals to the flowers.
of the isocarpous plants have almost distinct petals and tc
extent connect the Apopetalæ and the Gamopetalæ. The isoc
families culminate in the Ericaceæ, Primulaceæ and Styra
The great majority of the gamopetalous families belong to the
carpous division, the less specialized types with regular tubı
funnel-shaped corollas being the morning glories (Convolvul

[1] Campbell, D. H., "The Evolution of Plants," p. 213.

phloxes (Polemoniaceæ) and nightshades (Solanaceæ). The anisocarpous families culminate in the order Scrophulariaceæ, Compositæ and Caprifoliaceæ. The composite family is conceded by most botanists to be the most highly evolved and successful type of dicotyledonous plants and is represented in the diagram, therefore, as at the top of the system. It is not only the most successful type, but it is essentially a type of comparatively modern evolution.

It may be said in conclusion that many of the families represented in the chart occupy tentative positions. More thorough work must be done on many plants and plant families before we can feel assured of the true relationship of many of our most widely distributed families of dicotyledonous plants. All attempts at representing the affinities in a diagrammatic way are to be welcomed.

THE ARRAN'DA LANGUAGE, CENTRAL AUSTRALIA.

By R. H. MATHEWS, L.S.

(*Read October 5, 1906.*)

We encounter the southern limit of the Arranda language about Oodnadatta, the present terminus of the trans-continental railway from Adelaide towards Port Darwin. The language continues northerly from Oodnadatta to Charlotte Waters and onward to Glen Helen Cattle Station and Alice Springs, in the Macdonnell Ranges. The distance from Oodnadatta to Alice Springs is 347 miles along the public mail-coach road, but as the Arranda language extends some 50 miles farther north, we may say that the length of territory occupied by the people speaking that language, or dialects of it, is 400 miles, by a width of say 200 miles at the widest part—the greatest width being near the northern end in the Macdonnell Ranges and sources of the Finke River.

In 1875, more than thirty years ago, Mr. Christopher Giles, who was then station master at Charlotte Waters telegraph station, reported that the tribes in that neighborhood spoke the Arrinda (my Arranda) language and were divided into four sections, the names of which he stated, together with their intermarrying rules.[1] From information obtained from W. H. Willshire and other men who had resided many years in the district and were well acquainted with the natives, I communicated an article to this Society in 1899 showing a correct table of their intermarrying laws.[2] In 1900 I sent another article to this Society, with a map defining the southern boundary of the Arranda speaking people.[3]

In 1891, Rev. L. Schulze, a missionary at the aboriginal station at Hermannsburg, on the Upper Finke River, reported his discovery that the natives of that district were subdivided into eight sections. Four of these eight have the same names as the four sections men-

[1] "Folklore, manners, etc., of South Australian Aborigines," pp. 82–91.

[2] *Proc. Amer. Philos. Soc.*, XXXVIII., pp. 78–79.

[3] *Ibid.*, XXXIX., pp. 89–93, with map.

tioned by Mr. C. Giles, already referred to, with four new section names added, making eight divisions in all.[1] In 1899 I supplied a complete table showing the rules of marriage and descent among the eight sections of the Arranda.[2] The reader who wishes to study their sociology is invited to peruse the works quoted.

On the present occasion I shall endeavor to give a short account of the grammatical structure of the Arranda language. In 1890, Rev. H. Kempe, another missionary at Hermannsburg, published a grammar and vocabulary of this language,[3] and I propose to make use of some selections from his work, in addition to fuller information collected recently at my request by a capable friend and correspondent who resides in that district. It may be mentioned here that Mr. Kempe failed to observe the double form in the first person of the dual and plural in the pronouns which is now reported by me for the first time.

It may perhaps be as well to repeat that I was appointed by the Government of South Australia, a Land Surveyor in 1883, and a Justice of the Peace in 1884, both of which positions I still hold. By means of these appointments I have had opportunities which would not otherwise have occurred of carrying on my inquiries respecting the customs of the Aborigines in that State.

GRAMMAR OF THE ARRANDA LANGUAGE.

Articles.

There are no words strictly corresponding to the English articles *a* and *the*. The demonstrative adjectives, *this* and *that*, in their various aboriginal forms, supply the place of the definite article.

Nouns.

Number.—There are three numbers—the singular, dual and plural. Atua, a man; atuantatera, a couple of men; atuantirbera, several men. Another form of dual is: wora, a boy; woranangà, two boys. The latter form is used only for persons.

[1] "The Aborigines of the Upper and Middle Finke River," *Trans. Roy. Soc. South Australia*, XIV., 223–224.
[2] *Proc. Amer. Philos. Soc.*, XXXVIII., 76.
[3] *Trans. Roy. Soc. South Australia*, XIV., pp. 1–54.

Gender.—There are two ways of indicating gender in nouns—one of which consists of using different words for male and female, and the other by adding some word indicative of sex.

Atua, a man. Aragutya, a woman. Wora, a boy. Kwara, a girl. Katyia, a child of either sex. Among animals, words signifying "male" and "female" respectively are employed, as: Aranga kaluka, a buck kangaroo. Aranga mala, a doe kangaroo. Among some animals there is a name for the male, quite independent of the creature's usual name.

Case.—The principal cases are the nominative, causative, genitive, instrumental, dative and ablative.

Nominative. When the act remains with the subject, the noun is not declined. For example, atua indama, the man sleeps. Katyia lama, the child goes.

Causative. When a transitive verb is used, the noun takes a suffix, *la,* as: Worala gama, the boy eats. Apmala utnuma, the snake bites.

Genitive. This case is formed by adding *ka* to the nominative, as: Kata, father. Kataka wora, father's boy. The genitive case of a large number of nouns is effected by an abbreviated suffix corresponding to the person and number of the pronoun required, as: Katanuka, my father. Katankwanga, thy father. Katakura, his father; and so on through all the persons and numbers. See table of Pronouns.

Instrumental. This takes *lela,* as, ilupa, an axe. Ilupalela, with or by means of the axe.

The accusative is the same as the nominative, thus, Ta Kwatya nyuma. I water drink (I drink water). In some expressions the accusative takes the dative inflection, as: Atuala worana tukala, the man to-the-boy beat, resembling our expression "the man gave to) the boy a hiding."

The dative terminates in *na.* Ta Katyiana ndama, I to-the-child give.

Ablative. The case ends in *nga.* Era ulbarinya itity nga erbuma, he a boomerang from—mulga makes. Yinga wora nga tarama, I laugh for (the sake of) the boy.

Adjectives.

Adjectives follow the nouns which they qualify and are subject to the same declensions for number and case. Comparison is effected by using words signifying, " This is good—that is bad."

Pronouns.

Pronouns take inflexion for number, person and case. There are two forms in the first person of the dual and plural; one in which the person or persons addressed are included with the speaker, and another form in which the persons addressed are exclusive of the speaker. In the following table the first of these forms is marked " inclusive " and the second " exclusive." The " inclusive " form of the pronouns in the Arranda language has never been published by any other author. I was also the first to report the double " we " in the languages in the southeastern districts of South Australia:[1]

There are two district forms of the first person in the singular number, namely, *ta* and *yinga*. Ta is always used when connected with a transitive verb, as, ta tuma, I beat; ta ilkuma, I eat. Yinga is employed when connected with an intransitive verb, as, yinga indama, I sleep. Yinga lama, I go. In the second person singular there are also two forms of the pronuon—*unta* for use with transitive verbs, and *nga* with intransitive verbs. The third personal pronoun, *era*, is regularly declined in all the numbers.

The following is a full table of the *nominative* pronouns. " Transitive " and " intransitive " are respectively noted against the double forms of the first and second pronouns in the singular, to show the verbs with which they are employed. " Inclusive " and " exclusive " are marked against the double forms of the dual and plural.

Singular	1st Person	I, transitive	Ta
		I, intransitive	Yinga
	2d Person	Thou, transitive	Unta
		Thou, intransitive	Nga
	3d Person	He	Era
Dual	1st Person	We, inclusive	Ngilina
		We, exclusive	Ilina
	2d Person	You	Mbala
	3d Person	They	Eratara

[1] " The Bunganditch Language," *Journ. Roy. Soc. N. S. Wales*, XXXVII, 59-74.

Plural	1st Person	We, inclusive	Nganuna
		We, exclusive	Anuna
	2d Person	You	Rankara
	3d Person	They	Etna

The *possessive* pronouns are as under:

Singular	Mine	nukara	Thine unkwangara / Thine ngakara		His	ekurara
Dual	Ours, incl. ngilinakara / Ours, excl. ilinakara		Yours	mbalakara	Theirs	ekuraratera
Plural	Ours, incl. nganunakara / Ours, excl. anunakara		Yours	aragankara	Theirs	etnikara

These pronouns are generally used in the nominative case. For example, the question may be asked, "Whose spear is this?" and some one could answer, "Nukara (mine)." If used in a sentence, the dual and plural forms sometimes have a reflexive or reciprocal meaning, as the verb may determine. There are other forms of the pronouns, meaning "for me," "with me," "to me."

There is also a suffix, *arpa*, by annexing which to the personal pronouns gives them an emphatic meaning, thus:

Ta arpa, contracted to tarpa	Myself
Unta arpa contracted to untarpa	Thyself
Era arpa, contracted to erarpa	Himself

Another emphatic form is obtained by the suffix *atara* in the singular, which is altered to *watara* in the dual and plural. I (in place of anyone else) ta-atara; we, dual, ngilinawatara; we, plural, nganunawatara.

In regard to the double "we" in the dual, there are some variations, according to the relationship existing between the speaker and the person referred to. If a father speaks to his son he says Ngilaka instead of Ngilina, thus: "Ngilika araka larityika, we (dual) kangaroo-for must go. Emphatic forms are, Ngilanta, we (dual) only. Nganunanta or nganunantara, we (plural) only.

Demonstratives.—This, nana. These (dual), nanatera. These (plural), nanirbera. This is mine, nananuka or nanuka. That, tana; those (dl.), tanatera; those (pl.), tanirbera. Other shades of meaning are given by using nakuna and arina for "that." This, kena.

Interrogatives.—Who, ngana? Who did it, ngula? What,

iwuna? In the declension of nguna, the forms of the genitive, dative and ablative are inserted between the root and the termination of the word:

Genitive.	Ngu-*ka*-tera,	of which (dual)?
Dative.	Ngu-*an*-atera,	to which (dual)?
Ablative.	Ngu-*nga*-tera,	from which (dual)?

In the plural we would say, ngu-*ka*-irbera, or contracted to ngukirbera, of which? And so on.

Nguna unta nama, or ngununta nama, who thou art? Ngula nana nilknalinaka, who this stolen has?

Ntakina, how (in what way)? Ntakinya, how (many)? Ntakata, how (large)?

Indefinite pronouns. These are regularly declined. Arbuna, another. Arbunatera, others (dual). Arbunirbera, others (plural). Nintamininta, one by one or, each one.

There are no *relative* pronouns in the Arranda tongue and in this respect it resembles all other Australian languages with which I am acquainted.

VERBS.

The termination of the verb differs in each tense. For example, in the Indicative mood, the word *tuma* means, beats now; *tukala,* means, did beat; *tutyina,* shall beat. Any required number and person in any tense can be shown by using the proper pronoun. In other words, each tense form remains constant through all its numbers and persons. There are, however, modifications of the terminations of the verb in all the moods and tenses to express different shades of meaning, of which I shall give a few examples later on.

Verbs have the usual numbers, singular, dual and plural, each of which can be distinguished by the termination, if connected with a pronoun. When the proper pronoun is used, the dual or plural form of the verb may be omitted. There are three principal moods, the indicative, imperative and conditional. The form of the indicative has already been stated. The imperative is formed by adding *ai* to the stem, as, tu-ai, beat! The conditional mood is formed by the addition of *mara* to the stem, as, tu-mara, should beat. All the moods have a negative as well as a positive form, by infixing or adding *itya* or *gunia* to the positive.

Auxiliary Verbs.—The intransitive verb, *nama*, to sit, and having also the sense of our auxiliary, "to be," is employed as a suffix or augmentation in conjugating transitive verbs. The intransitive verb, lama, "to go," is similarly used. Sometimes the whole—sometimes only a part—of these auxiliaries are used as additions to active verbs.

In order to enable the reader to more easily understand the terminations or addenda to the transitive verbs, a short outline of the auxiliary, *nama*, will now be submitted. The present tense is given in full, but in the remaining tenses and moods the first person only of each number is taken.

INDICATIVE MOOD—*Present Tense.*

Singular	1st Person	I am	Yinga	nama
	2d Person	Thou art	Nga	nama
	3d Person	He is	Era	nama
Dual	1st Person	We, incl., are	Ngilina	narama
		We, excl., are	Ilina	narama
	2d Person	You are	Mbala	narama
	3d Person	They are	Eratera	narama
Plural	1st Person	We, incl., are	Nganuna	narirama
		We, excl., are	Anuna	narirama
	2d Person	You are	Rankara	narirama
	3d Person	They are	Etna	narirama

Past Tense.

Singular	1st Person	I have been	Yinga	nakala
Dual	1st Person	We, incl. or excl., have been	As in Present Tense	narakala
al	1st Person	We, incl. or excl., have been		narirakala

Future Tense.

ılar	1st Person	I shall be	Yinga	nityina
	1st Person	We, incl. or excl., shall be	As in Present Tense	narityina
ral	1st Person	We, incl. or excl., shall be		narirityina

IMPERATIVE MOOD.

Be! Sing., nai! Dual, narai! Plural, narirai!
Must be! Sing., nityika! Dual, narityika! Plural, nariritvika!

CONDITIONAL MOOD—*Present Tense.*

Singular	1st Person	I should be	Yinga	namara
Dual	1st Person	We, incl. or excl., should be	As in the Pronouns	naramara
ural	1st Person	We, incl. or excl., should be		nariramara

Future Tense (the Past is wanting).

Singular	1st Person	I should be	Yinga	nityinala
Dual	1st Person	We, incl. or excl., should be	As in the	narityinala
Plural	1st Person	We, incl. or excl., should be	Pronouns	narirityinala

Active Verbs.—The following is a fairly full conjugation of the transitive verb *tuma* or *tula*, to beat:

ACTIVE VOICE. INDICATIVE MOOD—*Present Tense.*

Singular	1st Person	I beat	Ta tuma
Dual	1st Person	We, incl., beat	Ngilina tula narama
		We, excl., beat	Ilina tula narama
Plural	1st Person	We, incl., beat	Nganuna tula narirama
		We, excl., beat	Anuna tula narirama

The negative form is: Singular, tutyikana. Dual, tula narityikana. Plural, tula narirityikana.

Past Tense.

Singular	1st Person	I have beaten	Ta tukala
Dual	1st Person	We, incl., have beaten	Ngilina tula narakala
		We, excl., have beaten	Ilina tula narakala
Plural	1st Person	We, incl., have beaten	Nganuna tula narirakala
		We, excl., have beaten	Anuna tula narirakala

The negative is formed in the singular by tutyimakana; in the dual by tula narityimakana; and in the plural by tula narirityimakana or tulta nityimakana.

Future Tense.

Singular	1st Person	I shall beat	Ta	tutyina
Dual	1st Person	We, incl., shall beat	Ngilina	tula narityina
		We, excl., shall beat	Ilina	
Plural	1st Person	We, incl., shall beat	Nganuna	tula narirityina
		We, excl., shall beat	Anuna	or tulta nityina

The negative form is: Singular, tutyigunia. Dual, tula narityigunia. Plural, tula narirityigunia or tulta nityigunia.

IMPERATIVE MOOD.

Beat (thou), tuai! Beat (you dual), tula narai! Beat (you plural), tula narirai! Another form, signifying to do the action quickly, is composed by inserting the syllable *-lba* between a duplication of the root, as, tu-lba-tuai, beat quickly. Let me beat, ta tuiai! Let us all, excl., beat, nganuna narireai!

The negative is: Singular, tutyala! Dual, tula narityala! Plural, tula narirityala!

Must beat: Singular, tutyika! Dual, tula narityika! Plural, tula narirityika! or tulta nityika! The negative of these three expressions is formed by adding *gunia*.

CONDITIONAL MOOD—*Present Tense*.

Singular	I should beat	Ta tumara	
Dual	We, incl., should beat	Ngilina	tula naramara
	We, excl., should beat	Ilina	or tulta namara
Plural	We, incl., should beat	Nganuna	tula nariramara
	We, excl., should beat	Anuna	

The negative is formed by substituting *ela* for the final *a*, as, Ta tumarela, I should not beat, and so on.

Future Tense (the Past is wanting).

Singular	I shall perhaps beat	Ta tutyinala	
Dual	We, incl., shall perhaps beat	Ngilina	tula narityinala
	We, excl., shall perhaps beat	Ilina	
Plural	We, incl., shall perhaps beat	Nganuna	tula narirityinala
	We, excl., shall perhaps beat	Anuna	or tulta nityinala

The negative takes the addition of *gunia*.

PARTICIPLES.

The present tense is formed by adding *manga* to the stem, the past by adding *mala*, the future by *tyinanga*. For example, namanga, while being; namala, after being; nityinanga, shall be being.

PARTICIPLES—*Present Tense*.

Singular	I am beating	Ta tumanga	
Dual	We, incl., are beating	Ngilina	tula naramanga
	We, excl., are beating	Ilina	
Plural	We, incl., are beating	Nganuna	tula nariramanga
	We, excl., are beating	Anuna	or tulta namanga

For the negative singular, tutyikananga. Dual, tula narityikananga. Plural, tula narirityikananga or tulta nityikananga.

Past Tense.

Singular	I was beating	Ta tumala	
Dual	We, incl., were beating	Ngilina	tula naramala
	We, excl., were beating	Ilina	
Plural	We, incl., shall be beating	Nganuna	tula nariramala
	We, excl., were beating	Anuna	or tulta namala

Negative: Singular, tumalikana. Dual, tula naramalamikana. Plural, tula nariramalamikana.

Future Tense.

Singular	I shall be beating	Ta tutyinanga	
Dual	We, incl., shall be beating	Ngilina	tula narityinanga
	We, excl., shall be beating	Ilina	
Plural	We, incl., shall be beating	Nganuna	tula narirityinanga
	We, excl., shall be beating	Anuna	or tulta nityinanga

Negative: Singular, tutyinagunia. Dual, tula narityinagunia. Plural, tula narirityinagunia.

MIDDLE VOICE—*Reflexive Form.*

The middle voice, in its reflexive form, describes an action which the subject executes directly upon himself. The sign of the reflexive is inserted in the middle of the verb, consisting of the particle *-la* or *-li*, according to the vowel in the adjacent syllable. For example, ta nukara tulama, I beat myself; to nukara tulaka, I have beaten myself; ta nukara tulityina, I shall beat myself. Ta is generally omitted, because nukara conveys the meaning of the first personal pronoun.

INDICATIVE MOOD—*Present Tense.*

Singular	I beat myself	Nukara tulama
Dual	We, excl., beat ourselves	Ilinakara tulala narama
Plural	We, excl., beat ourselves	Anunakara tulala narirama

Negative: Singular, tulityikana. Dual, tulala narityikana. Plural, tulala, narirityikana.

Past Tense.

Singular	I have beaten myself	Nukara tulaka or tulakala
Dual	We, excl., have beaten ourselves	Ilinakara tulala narakala
Plural	We, excl., have beaten ourselves	Anunakara tulala narirakala

Negative: Singular, tulityimakana. Dual, tulala narityimakana. Plural, tulala narirityimakana.

Future Tense.

Singular	I shall beat myself	Nukara tulityina
Dual	We, excl., shall beat ourselves	Ilinakara tulala narityina
Plural	We, excl., shall beat ourselves	Anunakara tulala narirityina

The negative is formed by adding *gunia,* as, nukara tulityigunia, and so on.

Imperative Mood.

Singular	2d Person	Beat thyself	Unkwangara tulai!
Dual	2d Person	Beat yourselves	Mbalakara tulala narai!
Plural	2d Person	Beat yourselves	Aragankara tulala narirai!

Negative: Singular, tulityala! Dual, tulala narityala! Plural, nariritvala!

Singular	I must beat myself	Nukara tulityika
Dual	We, incl., must beat ourselves	Ilinakara tulala narityika
Plural	We, incl., must beat ourselves	Anunakara tulala nariirityika

The negative is made by the addition of *gunia*.

CONDITIONAL MOOD—*Present Tense.*

Singular	I should beat myself	Nukara tulamara
Dual	We, excl., should beat ourselves	Ilinakara tulala naramara
Plural	We, excl., should beat ourselves	Anunakara tulala nariramara

The negative is formed by adding *gunia* to the positive.

Future Tense (the Past is wanting).

Singular	I shall beat myself	Nukara tulityinala
Dual	We, excl., shall beat ourselves	Ilinakara tulala narityinala
Plural	We, excl., shall beat ourselves	Anunakara tulala nariritvinala

The addition of -*gunia* constitutes the negative.

PARTICIPLES—*Present.*

Singular	I am beating myself	Nukara tulamanga
Dual	We, excl., are beating ourselves	Ilinakara tulala naramanga
Plural	We, excl., are beating ourselves	Anunakara tulala nariramanga

Negative: Singular, tulityikananga. Dual, tulala narityikananga. Plural, tulala nariritvikananga.

Past Tense.

Singular	I was beating myself	Nukara tulamala
Dual	We, excl., were beating ourselves	Ilinakara tulala naramala
Plural	We, excl., were beating ourselves	Anunakara tulala nariramala

Negative: Singular, tulamalikana. Dual, tulala naramalamikana. Plural, tulala nariramalamikana.

Future Tense.

Singular	I should beat myself	Nukara tulityinanga
Dual	We, excl., should beat ourselves	Ilinakara tulala narityinanga
Plural	We, excl., should beat ourselves	Anunakara tulala nariritvinanga

The negative is expressed by adding *-gunia* or *-itya.*

RECIPROCAL FORM.

This form of the middle voice is a modification of the verb which applies itself to a case where two or more persons reciprocally beat each other, and is consequently limited to the dual and plural numbers. It is known by the termination *rama* for the dual and *rirama* for the plural. Example, ilina turama, we (dual) beat each other; anuna turirama, we (plural) beat each other. A few examples in the third person of the plural will be sufficient to show how the verb is declined in the different moods and tenses.

INDICATIVE MOOD—*Present Tense.*

They, pl., beat each other, Etnikara turirama.
They, pl., beat not each other, Etnikara turirityikana.

Past Tense.

They, pl., have beaten each other, Etnikara turirakala.

The negative form of the word is turirityimakana.

Future Tense.

They, pl., shall beat each other, Etnikara turirityina.

The negative consists of adding *gunia.*

IMPERATIVE MOOD.

Beat each other, aragankara turirai!

They, pl., must beat each other, etnikara turirityika.

CONDITIONAL MOOD—*Present Tense.*

They, pl., should beat each other, Etnikara turiramara.

Future Tense. (Past is wanting.)

They, pl., should beat each other, Etnikara turirityinala.

PARTICIPLES—*Present.*

They, pl., are beating each other, Etnikara turiramanga.

Negative, turirityikananga.

Past Tense.

They, pl., were beating each other, Etnikara turiramala.

Negative, turiramalikana.

Future Tense.

They, pl., should beat each other, Etnikara turirityinanga.

The negative is expressed by *gunia* or *itya*.

There are modifications of the verbal suffixes of the past tense to indicate the immediate past, the recent past, and the remote past. Similar modifications exist for the proximate, or more or less distant future. There are likewise forms of the verb to express repetition or continuance of the act described, and many other complexities, which must be only briefly referred to in the present article. In these respects the Arranda resembles the Kamilaroi, Wiradyuri, Thurrawal and other Australian tongues, the grammars of which have been published by me.[1]

Tutyigunala, to beat by and by.
Tutyilbitnima, to come to beat.
Tutyalbuma, returned to beat.
Tutyikamanityikana, to beat not again.
Tualbuntama, to beat running away.
Tuatalalbuma, to beat on the way home.
Tulinya tulindama, to beat always.
Tulatulauma, to beat seldom.
Tuatna lama, to beat on arrival at another place.

Adverbs.

Derived adverbs, corresponding with English adverbs ending in *ly*, are formed by adding the particle *la* to adjectives, as, Era ekaltala erguma, he firmly holds.

Adverbs of time: Now, lata. Soon, lilika. Yesterday, tmurka. Day before yesterday, tmurkarbuna. To-morrow, ingunta. Long ago, imanka. By and by, anma. What time? ilangara? Always, kuta.

Of place: Here, nana. There, arina. Near, itinya. Far, longa. Where? ntala? Whither? ntauma? Whence? ntananga. Thither, nauna or arinuna.

[1] *Journ. Anthrop. Inst.*, London, XXXIII, 259–283. *Ibid.*, XXXIV, 284–305. *Journ. Roy. Soc. N. S. Wales*, XXXV, 127–160.

Of number: Once, ninta ranga or ninta ngara. How many times, ntakinyaranga. Twice, tera ranga. Sometimes, urbutya ranga.

Of order: The first, arugula. The last, inkana. Between, mbola.

Of quantity: Much, nyara. Little, kurka. Enough, kala. So, lakina. Like, ngera. More, wota.

Of quality: Slowly, monjala. Badly, kuna. Quickly, parpa. Good or well, mara.

Of affirmation: Certain or true, tutna. Of course, wakuia. Yes, wa or wabala.

Of negation: No or none, itya. None or not, gunia and lira.

Prepositions.

There are two sorts of prepositions, one class comprising separate words, and the other consisting only of small particles annexed to the nouns—both being placed at the end of the word to which they belong. The separate words are as follows:

In front, ulara. Behind, topala. Outside, gatala. Between, mbobula. Other side, ntuara. This side, nunkara. Beside, nkelala. Close by, itinyawara. Through, ntuarintyirka. Upon, katningala. Over, katningalagana. Down, kwanakala. Inside, kwanala.

The prepositions annexed to nouns as suffixes are: Upon, into, una. Example, kwatya-una, abridged to kwatyuna, into the water. Bira-una (biruna), upon the tree. By or with, lela. E. g., atualela, by the man. At, la, as Tyoritya-la, at Alice Springs. With or along with, gata. Without, raba. For, or in exchange, gityala. For (the sake of), kaguia. On (as, on a nail), kieka. From, out of, ibena or ibera.

Conjunctions.

This languages possesses very few conjunctions, most of them being combined with the verb. There is not even a proper word for the copula, and the following are the only examples found: Too, also, tuta or urungara. Yet (nevertheless), etalinya. But, bula. Only, wara. The suffix, *-nta,* also means only. As, than, ngetyina. Then, gurunga.

Interjections.

Hear! aai! I am sorry! apu! Behold! erai! Woe! tyikabai. Indeed, verily, nturbai! Calling attention, tyikai!

NUMERALS.

Ninta, one. Tara, two. Several, urbutya.

ARRANDA VOCABULARY.

The following list of 160 of the most commonly used the Arranda language has been written down from the r the native speakers by one of my most valued correspo that locality.

Family Terms, etc.

ENGLISH.	ARRANDA.
Man	Atua
Mankind	Rela or erila
Father	Kata or Knaia
Elder brother	Kalya
Younger brother	Tyia or ityia
Boy	Wora
Woman	Aragutya
Mother	Maia
Elder sister	Kwaia
Younger sister	Tyia or ityia
Girl	Kwara
Infant (neuter)	Katyia
Doctor	Ngankara
Wise man	Knarabata
Soul	Guruna and lta
Wife	Noa-iltya
Good spirits	Tuanyirika
Evil spirit	Erinya
Ghost	Mangabura
Avenging party	Knenka

Parts of the Human Body.

ENGLISH.	ARRANDA
Head	Kaputa
Eyes	Alkna
Nose	Ala
Tongue	Lenya or
Teeth	Detya
Ears	Ilba
Hand	Iltya or
Foot	Inka
Blood	Alua
Penis	Parra
Vagina	Atna
Anus	Gola

Inanimate Nature.

ENGLISH.	ARRANDA.
Sun	Alinga or rerka
Moon	Taia or tninya
Full moon	Ilkapala
Fire	Ura
Water	Kwatya
Camp (general)	Tmara
Smoke	Kwata
Rock	Tĕnta
A stone	Pata
Sand	Ulbaia
The ground	Ala or Arila
Pipe-clay	Ikuna
Red ochre	Ulba tataka
Milky way	Ulbaia
Pleiades	Rargua
Orion	Kuralya
Southern cross	Erityinka
Creek or river	Lara
Shadow	Ullincha
Rainbow	Umbulara
Sky	Altyira
Men's camp	Nkanya
Women's camp	Lukara
Meat food	Garra
Vegetable food	Mana
Grass-seed cakes	Egalla
Spinifex gum	Nurbma
Home of souls	Laia

Animals.

ENGLISH.	ARRANDA.
Opossum	Ntāna
Porcupine	Yuta or inalinga
Rock Wallaby	Aroa
Red Kangaroo	Ara
Grey Kangaroo	Aranga
Bat	Ulbulbana
Tame dog	Knulya
Wild dog	Knulya itnora
Emu	Ilia
Eaglehawk	Eritya
Pelican	Kabilyalkuna
Crow	Ngapa
Carpet Snake	Renina
Iguana	Tyunba
Louse	Ita or itya
Native cat	Lukaringa
Bandicoot	Tnunga
Turkey	Itoa
Pheasant	Ngamara
Plover	Bilbilpa
Ring-neck parrot	Erapitya
White cockatoo	Kakalala
Lizard	Ilancha
Scorpion	Natata

Fish	Irbunga
Mosquito	Wunia
Locust	Alknenera
Honey ant	Yeramba
Bull-dog ant	Tyanka
Caterpillar	Weba
Centipede	Inbirka

Implements, etc.

English.	Arranda.
Stone tomahawk	Lanya or ilapa
Stone knife	Karitya
Stone knife	Irkala
Stone knife	Katua
Shield	Lkuta
Spear	Tyata and ulkuta
Womera	Mera
Boomerang	Ulbarinya
Wooden trough	Tyelya
Yamstick	Tnama
A bag	Taua
Skin bag	Larntua
Brow-band	Chilarra
Arm-bands	Kaltyia
Nose peg	Lalkara
Necklace	Gulitya
Music tube	Albirra
Bullroarer or amulet	Tyurunga

Trees and Plants.

English.	Arranda.
Grass tree	Lonkura
Desert oak	Irgapa
Red-gum tree	Para or bira
Beefwood	Iltyantya
Bullrushes	Inkua
A flower	Antata

Adjectives.

English.	Arranda.
Large	Knara
Small	Kurka
Straight	Aratya
Crooked	Inkutinkuta
Good	Mara
Bad	Kunna
Hungry	Ngaiala
Stinking	Intita
Quick	Parpa or intira
Afraid	Ningalkua
Short	Botera
Strong	Ekalta
Plump	Andera
Alone	Egna
Cold	Dana

Thirsty	Ankatala
Sick	Ekna
Tired	Borka
Deep	Ipita

Verbs.

English.	Arranda.
Stand	Tnama
Sit	Nama
Walk	Lama
Eat	Ilkuma
Drink	Nyuma
Give	Ndama
Talk	Ankama
Beat	Tuma
Throw	Womma
Carry	Ngama
Bite (as dogs)	Utnuma
Bite (in eating)	Kokuma
Weep	Itnima
Go	Lama
Seek	Yaralama
Come	Bityima
Lift up	Tyunama
Dream	Altyirerinya
Laugh	Tarama
See	Airima
Sing	Ilima
Hear or listen	Talakauma

Numerals.

English.	Arranda.
One	Ninta
Two	Tara
Several or some	Urbutya
Many	Knira and nyara

Stated Meeting October 4, 1907.

President SMITH in the Chair.

The decease was announced of the following members:

John H. Packard, M.D., at Atlantic City on May 21, 1907, æt. 74.

Mrs. Elizabeth Agassiz, at Cambridge, Mass., on June 27, 1907, æt. 85.

Richard Meade Bache, at Philadelphia on July 17, 1907, æt. 77.

Professor Angelo Heilprin, at New York on July 17, 1907, æt. 54.

William Thomson, M.D., at Philadelphia on August 3, 1907, æt. 74.

Charles Stewart Wurts, M.D., at Media, Pa., on August 14, 1907, æt. 78.

Professor John Pomialowsky of St. Petersburg.

The following papers were read:

"New Results in Electrolysis," by LILY G. KOLLOCK and EDGAR F. SMITH (see page 341), which was discussed by Dr. Keller, Mr. Whitfield, Prof. Goodspeed, Prof. Snyder and Dr. Tuttle.

"A Study of Correlations Among Terrestrial Temperatures, as Indicated by Fluctuations in the Sun's Thermal Radiation," by PROF. SIMON NEWCOMB (see *Transactions*, N. S. Vol. XXI, p. 309), which was discussed by Prof. Doolittle, Prof. Snyder and Prof. Haupt.

"Language of the Burdhawal Tribe in Gippsland, Victoria," by R. H. MATTHEWS. (See page 346.)

NEW RESULTS IN ELECTROLYSIS.

By LILY G. KOLLOCK and EDGAR F. SMITH.

(*Read October 4, 1907.*)

(Contribution from the John Harrison Laboratory of Chemistry.)

Since it was observed that anions could readily be estimated by means of the mercury cathode and rotating anode (*Jr. Amer. Chem. Soc.*, **29**, 447), the thought occurred that anions might also be separated by the same means. With this end in view, the following study was undertaken. Potassium ferrocyanide and potassium ferricyanide were the salts used in the work. It was decided to conduct experiments in order to find any difference which might exist in the decomposition pressures. If such conditions did exist, then separations might be effected by this procedure.

The experiments were carried out in the same apparatus and following the directions given in the paper mentioned above. A solution of potassium ferrocyanide, containing in 50 c.c., 0.1316 gram of the salt, under a pressure of 4.5 volts and a current of 0.15 ampere at the beginning, falling to 0.02 ampere at the end, in one hour gave the total $Fe(CN)_6$ present. This was equal to 0.0661 gram. The ferricyanide solution, containing 0.1070 gram of the salt, equivalent to 0.0636 gram of $Fe(CN)_6$, was subjected to the same current, giving the required amount of anion in about the same period of time.

When trying the effect of lower currents, for example 1.5 volt and 0.07–0.02 ampere, upon potassium ferricyanide, it was observed that there was no decomposition of the amalgam in the outer cell. But when phenolphthalein was added to the contents of the inner cell, a strong alkaline reaction was indicated. The silver anode had increased 0.0467 gram after an hour's action of the current, while the amount of potassium present was only 0.0156 gram instead of 0.0253 gram, the equivalent quantity. It was decided to repeat

s work l: er and to seek for an explanation of its discrepancy, d in the meantime to ascertain the effects of lower currents upon th potassium ferrocyanide and potassium ferricyanide.

A thermopile was used as the source of the current in all the equent work. A water rheostat was constructed from a battery jar about twelve inches high by 9″ by 6″ cross section, containing a dilute solution of sodium chloride in which were immersed two lead plates six inches square. The resistance was regulated by raising or lowering the plates in the solution. The voltmeter, graduated to one thirtieth of a volt, and the milliammeter were continually in the circuit.

Potassium ferrocyanide was acted upon by a current of 0.4 volt. This gave a current unappreciable on the milliammeter. It acted for an hour and a quarter. There was no decomposition observed in the outer cell. Titration of the contents of the inner cell with N/10 hydrochloric acid showed the presence of 0.0039 gram of potassium. The anode increased in weight by 0.0052 gram. This is in about equivalent quantities. (The theoretical equivalent of potassium would be 0.00382 gram.) By using a current of 0.13–0.16 volt, there was no evidence of decomposition, either in increase in the weight of the anode or evidence of potassium hydroxide in either cell, with phenolphthalein as indicator. Even 0.02 volt in one hour had not effected any change, but with 0.23 volt, the anode, after an hour's action of the current, had increased 0.0004 gram, and a faint pink color was observed when phenolphthalein was added to the solution in the inner cell. This was dispelled by a fraction of a drop of N/10 hydrochloric acid. With a current of 0.266 volt, the anode after the same period of time had increased 0.0014 gram. When 0.3 volt was employed 0.0022 gram of $Fe(CN)_6$ had separated on the anode and 0.00039 gram of potassium was found in the solution. A current of 0.4 volt showed 0.005 gram of $Fe(CN)_6$ and 0.00107 gram of potassium, while 0.5 volt gave 0.0064 $Fe(CN)_6$ and 0.0041 gram of potassium.

The following table shows the effect of increase in the current:

Current in Volt.	$Fe(CN)_6$ in Gram.	Potassium in Gram.
0.23	0.0004	......
0.266	0.0014	......
0.3	0.0022	0.00039
0.4	0.005	0.00107
0.5	0.0064	0.0041
0.66	0.0073	0.0054
0.83	0.0164	0.01209
1.0	0.0174	0.0117

The milliammeter in the last two experiments showed a current of one milliampere at the beginning, which at the end had fallen to 0.0005 ampere.

There appears therefore to be no decomposition of potassium ferrocyanide by currents lower than 0.23 volt.

Experiments were then conducted in order to ascertain the effects of low currents upon potassium ferricyanide. The salt used was recrystallized several times. The solution contained 0.1323 gram of the salt. This was equivalent to 0.0471 gram of potassium and 0.0852 gram of $Fe(CN)_6$. There was no evidence of potassium hydroxide in either cell after the current, having an electromotive force of 0.3 volt and 0.5 milliampere, had acted for half an hour. With 0.66 volt, giving a current of 0.002 ampere at the beginning of the experiment acting for an hour, the anode increased 0.0309 gram in weight and but 0.0039 gram of potassium was found. These experiments confirmed the observations made upon potassium ferricyanide at the beginning of the work. The increase in weight of the anode was out of proportion to the amount of potassium present. Several other experiments with low currents gave similar results. For example, a current of 0.4 volt, after one half hour's action of the current showed only a small amount of potassium but 0.0279 gram of $Fe(CN)_6$. When a current of 0.1 volt was passed, the anode, after an hour's action of the current, increased 0.0223 gram, but there was no evidence of potassium hydroxide in the solution.

An explanation of these results was sought. As the solution changed color, and showed the presence of ferrocyanide on testing with ferric chloride, after electrolysis, it was thought that ferricyanide might first be reduced to ferrocyanide. Four molecules of

ferricyanide would form three molecules of ferrocyanide with the splitting off of one radical, thus:

$$4K_3Fe(CN)_6 = K_{12}Fe_4(CN)_{24}$$
$$3K_4Fe(CN)_6 = K_{12}Fe_3(CN)_{18}$$
$$\overline{\phantom{K_{12}}Fe(CN)_6}$$

This would therefore give

$$4K_3Fe(CN)_6 : Fe(CN)_6 :: 0.1323 \text{ gram} : 0.0213 \text{ gram}.$$

By constant and careful observation of the voltmeter, it was thought the end of this reaction could be detected.

In the first experiment with this end in view, a current of 0.4 volt and 0.001 ampere was passed through the solution of potassium ferricyanide. There was a constant tendency of the voltage to rise. But by throwing in resistance this was maintained at 0.4 volt, the current falling to 0.0002 ampere. In about thirty minutes the voltage was observed to fall slightly. The current was then interrupted. The anode had increased 0.0217 gram and there was no potassium hydroxide detected in either cell. Subsequent experiments, carrying out the same plan, gave 0.0211, 0.0214, 0.0209, 0.0213 gram increase in weight of the anode. The operations required constant and careful attention, inasmuch as the point at which the change takes place is momentary. The speed of the anode in all cases was about seventy-four revolutions per minute. The time required for the reaction varies slightly with the conditions, as may be observed from the following table:

Current in Ampere.	Volts.	Time in Minutes.	$Fe(CN)_6$ in Gram.
0.001–0.0002	0.4	30	0.0217
0.001–0.0002	0.4	30	0.0211
0.001–0.0002	0.36–0.4	35	0.0214
0.001–0.0002	0.4	35	0.0209
0.002–0.0002	0.4	22	0.0228 (trace of K)
0.002–0.0005	0.4	19	0.0208
0.002–0.0005	0.4	19	0.0213

It therefore seems probable that potassium ferricyanide is at st reduced to ferrocyanide by the current.

That reduction should occur at the anode or in the anode com-rtment is anomalous. It would perhaps be better to say that a tassium amalgam had formed and in its decomposition hydrogen d caused the reduction of the ferricyanide.

UNIVERSITY OF PENNSYLVANIA.

...E OF THE BIRDHAWAL TRIBE, IN GIPPSLAND, VICTORIA.

By R. H. MATHEWS, L.S.

(Read October 4, 1907.)

In the following contribution I shall endeavor to give an outline of the grammatical structure of the language of the Birdhawal tribe, prepared from notes taken by myself among the survivors of these people. Their hunting grounds were mainly in the extreme eastern corner of the State of Victoria, but they also occupied a small strip of country within the New South Wales frontier. Their boundary may be approximately defined as follows: Commencing on the sea coast, at Cape Conron, and reaching thence along the coast to Mullacoota Inlet, including the following rivers and their tributaries—Bemm, Cann, Thurra, Wingan and Genoa. The Birdhawal territory extended inland from the sea coast to Bonang, Delegete, Craigie, and some other places in that district.

It will be seen that the foregoing description crosses the boundary between New South Wales and Victoria, and takes in the head waters of the Queenboro, Bondi and Nungatta creeks.

The initiation ceremony of the Birdhawal tribe, known as the *Dyerrayal*, has been described by me with considerable fullness in a contribution to the Anthropological Society of Vienna,[1] to which the reader is referred.

All along their western side, the Birdhawal are met by the Kurnai tribe, for a description of the extent of whose territory the reader is referred to my article on "The Victorian Aborigines," which I contributed to the Anthropological Society of Washington, U. S. A., in 1898.[2] For a short grammar and vocabulary of the Kurnai, see my "Aboriginal Languages of Victoria," contributed to the Royal Society of New South Wales in 1902.[3]

[1] Mitteil. d. Anthrop. Gesellsch. in Wien. Band XXXVII, 1907.

[2] *American Anthropologist*, XI., pp. 326–330, with a map showing the distribution of the Native Tribes of Victoria.

[3] *Journ. Roy. Soc. N. S. Wales*, XXXVI., pp. 71–106.

Among the Kurnai, *bra* means mankind, but *kurnai* or *kunnai* distinguishes one of their own men. In the Birdhawal, *mawp* means mankind, whilst *gidyang* signifies a man of their own tribe. Detachments of the Birdhawal community who inhabited the densely timbered tracts, were called *waggarak*. The Birdhawal call their own dialect *mŭk-dhang*, but they distinguish the dialect of the Kurnai as *gūnggala-dhang*. The termination *dhang* in both instances means "mouth," and is symbolical of speech. It may also be mentioned that the Kurnai call their own local dialect *mŭk-dhang*, and that of the Birdhawal *kwai-dhang*. *Mŭk* means good or great, and *kwai* signifies rough; I forget the meaning of *gūnggala*.

If we take the whole of that portion of the State of Victoria lying to the east of the 146th meridian of longitude, and situated between the sea coast and the great dividing range or Australian Alps, we find that the language of the native tribes has the same grammatical structure. This region of Victoria is commonly known as Gippsland, and the language prevailing over the whole area is the Birdhawal, or dialects of the Birdhawal. A glance at a map of Victoria will show that this tract of country embraces the entire sea coast from Cape Howe westerly to Waratah Bay, and extends thence northerly to the great dividing range.

The social organization of the Birdhawal is substantially the same as that of the Woïwurru, Bunwurru, Thagungwurru and other tribes, which has been described by me elsewhere.[1] The social structure of the Birdhawal is also analogous to that of the Thurrawal and kindred tribes situated to the northeast of them in New South Wales, with which I have already dealt in several publications.

Orthography.

The system of orthoëpy adopted is that recommended by the Royal Geographical Society, London, but a few additional rules of spelling have been introduced by me, to meet the requirements of the Australian pronunciation.

Eighteen letters of the English alphabet are sounded, comprising

[1] *Journ. Roy. Soc. N. S. Wales*, XXXVIII., pp. 297–304.

thirteen consonants, namely: *b, d, g, h, k, l, m, n, p, r, t, w, y,* and five vowels: *a, e, i, o, u.*

As far as possible, vowels are unmarked, but in some instances, to prevent ambiguity, the *long* sound of ā, ē, ī, ō and ū are given as ere represented. Where the *short* sound of these vowels was otherwise doubtful, they are marked thus: ă, ĕ, ŏ and ŭ.

It is frequently difficult to distinguish between the short sound of *a* and that of *u*. A thick sound of *i* is occasionally met with, which closely resembles the short sound of *u* or *a*.

B has an intermediate pronunciation between its proper sonant sound and the surd sound of *p*. The two letters are practically interchangeable.

G is hard in all cases, and often has the sound of *k*, with which it is generally interchangeable.

W, when it commences a syllable or word, has its ordinary English sound. The sound of *wh* in our word "what" has no equivalent in the native tongue. When *W* occurs in the middle or at the end of a syllable, it is pronounced as in the English words "pawn" and "law" respectively.

Ng at the beginning of a word or syllable has a peculiar nasal sound as in the English word "singer." If we alter the syllabification of this word and write it "si-nger," then the *ng* of "-nger" will represent the aboriginal sound. Or if we take the expression "hang up" and change it into "ha-ngup," and then pronounce it so that the two syllables melt into each other, the *ng* of "-ngup" will also be the sound required. At the end of a syllable, *ng* has the sound of *ng* in king.

The sound of the Spanish ñ frequently occurs. At the beginning of a word or syllable it is given as *ny*, but when terminating a word the Spanish letter ñ is used.

Dh is pronounced nearly as *th* in "that," with a slight sound of *d* preceding it. *Nh* has likewise nearly the sound of *th* in that, with a perceptible initial sound of the *n*.

Th is frequently used at the commencement of a word instead of *dh*, and in such cases an initial *t* sound is substituted for that of the *d*. *Dh* and *th* are generally interchangeable. At the beginning

of a word our English sound of *d* and *t* seldom occurs; it is generally pronounced *dh* or *th*, in the way just explained.

A final *h* is guttural, resembling *ch* in the German word "joch."

Y at the commencement of a word or syllable preserves its habitual sound.

R in general has a whirring sound, at other times it is rolled, and occasionally the English value is assigned to it.

T is interchangeable with *d*, *p* with *b*, and *g* with *k*, in most of the words in which these letters are used.

Ty or *dy* at the commencement of a syllable or word has nearly the sound of the English *j* or Spanish *ch*, thus *-dya* in the word wom-ba-dya, closely resembles *cha* or *ja*.

Some native words terminate with *ty*, as *brety*, the hand. This word can be pronounced exactly by assuming *e* to be added to the final *y*, making it *bret-ye*. Then commence articulating this word, including the *y*, but stopping short without sounding the added *e*. An approximate pronunciation can also be obtained by substituting *ch* for the *y*, making it *bretch*, but omitting the final hissing sound when pronouncing it. In some of the words in the vocabulary I have given the terminal letters *tch* instead of *ty*, as being more easily mastered by lay readers.

In order to express the native sound of some words, I have used the initial letters *wr* and *mr*. The word *wrŭk*, the ground or earth, can be got exactly by making it *wu-rŭk'*, and then pronouncing it as one syllable, with the accent on the last letter. *Wring*, the ear, can be similarly articulated. *Mring*, the eye, can be pronounced by making it *mu-ring'*, and treating it as one syllable. *Mrety* or *mretch*, fire, can be pronounced in the same way.

Articles.

The indefinite article, "*a*," is not represented; but the demonstrative pronouns, in their numerous modifications, supply the place of the difinite article, "*the*." The adverbs "here" and "there," in their several native forms are treated as demonstratives, and are then substitutes for the definite article. Many of them are subject to inflection for person and number, and some have causative suffixes.

NOUNS.

Nouns are subject to variation on account of number, gender and case, the inflection being effected by means of postpositions.

Number.—There are three numbers. The singular number denotes one; the dual, two or a pair; the plural number, more than two. Ngurka, a native bear. Ngurkabulang, a couple of bears. Ngurkawamba, several bears.

Gender.—In the human family sex is distinguished by the employment of different words. Mawp, a man. Kurragan, a woman. The gender of animals is distinguished by the words *brangula* and *yuggana,* placed after the name of the animal. Ngurka brangula, a male bear; ngurka yuggana, a female bear.

For a few of the animals, a specific word represents the male, without naming the creature, but in the case of the female, the animal's name must be stated, followed by the distinguishing word, *yuggana.* When the name of any animal is mentioned, without some word signifying the sex, the masculine gender is understood.

Case.—The cases are indicated by inflections—the following being the principal.

Nominative: This case merely names the subject, and is without inflection. Gungarang, an opossum; burru, a kangaroo; buran, a spear.

Causative: This represents the subject in action, and is used with a transitive verb. Mawpu gungarang bundan, a man an opossum killed. Kurraganu kalkun mangan, a woman an eel caught it.

Genitive: A peculiarity of this case, which I was the first author to report in any Australian language,[1] is that the property and the proprietor each take a suffix. Bagurdyu mawpa, a man's boomerang.

Every object or article over which ownership can be exercised is subject to inflection for person and number; as, bagurdya, my boomerang; bagurngunna, thy boomerang; bagurnga, his boomerang, and so on. The dual and plural contain "inclusive" and "exclusive" forms in the first person.

[1] "The Thoorga Language," *Queensland Geographical Journal* (1901), Vol. XVII., pp. 52–53.

Instrumental: When an instrument is the remote object of the verb, it takes the same suffix as the causative. Mawpu burru bundan buranu, a man a kangaroo killed with a spear.

Accusative: This is the same as the nominative.

There are inflections to denote motion towards or away from any place or thing. Banggea, towards a camp. Bangga, away from a camp.

Adjectives.

Adjectives succeed the nouns they qualify and take the same inflections for number and case. The suffix is often omitted from one of the words, leaving the noun only, or the adjective only, to indicate the declension. Comparison is effected by two positive statements, such as: This is good—that is bad.

Pronouns.

Pronouns are inflected for persion, number and case, but are without gender. The following are examples in the singular number of the nominative and possessive pronouns:

Singular	First person	I	Ngaiu	Mine	Ngaindya
	Second person	Thou	Ngindu	Thine	Ngingunna
	Third person	He	Mindha	His	Ngaianga

In the dual and plural forms of the pronouns there is a double "we" in the first person, marked "inclusive" and "exclusive" respectively.

Dual	First person	We, inclusive	Ngallu
		We, exclusive	Ngallung
	Second person	You	Ngindubul
	Third person	They	Mindhabullong
Plural	First person	We, inclusive	Ngangun
		We, exclusive	Ngangunnang
	Second person	You	Ngindigan
	Third person	They	Mindhagullang

These full forms of the pronouns are not much used, except in answer to a question, or assertively. If some one ask, "Who is going hunting?" a man may answer, Ngaiu, "I am," or Ngallung, "we (dual exclusive) are." If an inquiry be made, "Whose food is this?" some one may reply, pointing to a certain individual, Ngaianga, "his," and so on.

There is but little regularity in the pronouns of the third person in any of the numbers. This is owing to a word more or less different being used to express whether the person meant is near, or at some distance; whether he is going away from, or coming towards, the speaker; whether he is in the front, or in the rear, and so on.

Interrogatives: Who, nganinde? What, nganna? How many, nau-wun?

Demonstratives: Dyinda, this or here. Mindha, that or there. There it is, munda. These demonstratives are declinable for the dual and plural numbers.

There are likewise forms of the pronouns meaning "for me," "from me," "with me," etc., which extend through all the persons and numbers.

Verbs.

Verbs have the usual numbers, persons and moods, as well as an inclusive and exclusive form in the first person of the dual and plural. The following is a short conjugation of the verb "to strike or beat." In most Australian languages the word for striking also means to kill.

Indicative—Singular.

Person.	Present.	Past.	Future.
First person	Bundanetch	Bundadya	Bundinga
Second person	Bundadu	Bundani	Bundinyin
Third person	Bunda	Bundan	Bundin

Although the inflections on the above words sufficiently indicate the person to a native listener, there would be no objection to prefixing the full pronoun, as, Ngaiu bundanetch, Ngindu bundadu, and so on.

The future tenses of the first person of the dual and plural are as under:

Dual	We, inclusive, shall beat	Bundinyil
	We, exclusive, shall beat	Bundinyillung
Plural	We, inclusive, shall beat	Bundingun
	We, exclusive, shall beat	Bundingunnang
Imperative	Beat	Bundin!

Reflective.

The reflective form of the verb describes an action which the subject executes directly upon himself:

I am beating myself, Bundhattharanetch. All the remaining persons and numbers can be inflected in the same way.

Reciprocal.

There is a form of the verb to express that two or more persons are reciprocally doing the act described:

We, dual, are beating each other, Bundhaiadyillung.

We, plural, are beating each other, Bundhaiagundhiang; and so on for the second and third persons of the dual and plural.

In the past and future tenses of verbs, there are variable terminations to indicate that the act described was done in the immediate, recent, or remote past; or that the act will be performed in the proximate, or more or less distant future. That there was, or shall be, a repetition or continuance of the action, and other modifications of the verbal suffixes, which must be passed over for the present.

Owing to the several inflections of the verb in the past and future tenses just referred to, it is often found convenient, especially when speaking in the dual and plural, to prefix a complete pronoun from the table of pronouns. This leaves the termination of the verb freer for the various suffixes required to convey the different meanings.

There is no special form for the passive voice. The sentence, "a man was kicked by an emu," would be expressed by the paraphrase, "an emu kicked a man."

Adverbs.

Yes, nyung. No, kalligo. To-day, wadya. This evening, wariñ. Yesterday, buna. To-morrow, mimburiñ. By and by, kalla. Some time back, buni-i. Here or this, dyinda. There or that, mindhi. Away yonder, bubburike. Where, ngulman. Dhũnggo, here. I am here, dhũnggomanetch; thou art here, dhũnggomangunna; he is here, dhũnggomana.

Prepositions.

The equivalents of our English prepositions are in some cases separate words, but are also frequently expressed by a verb, as in the Dyirringañ[1] and other languages.

[1] *Journ. Roy. Soc. N. S. Wales* (1902), Vol. XXXVI., p. 166.

›ositions can be inflected for person and number. In dhangullindya. In front of thee, dhangullingunna. m, dhangullana.

NUMERALS.

ı-ge or gu-dug. Two, bolang. Several, bunganbandhak.

BIRDHAWAL VOCABULARY.

vocabulary comprises 285 of the most commonly used the Mŭkdhang speech, every item having been noted down ıf from the mouths of the natives. Words of the same kind are ped under common headings. It is thought that this arrangement will be more convenient for reference and comparison than if tabulated alphabetically.

Family Terms.

Mankind	mawp	Novice	dhŭrtungurriñ
A man	gidyang	A woman	kurragan
Old man	muyulung	Wife	bulamirnda
Husband	bulamirnda	Small girl	mullangan
Song-maker	birrarak	Elder sister	mamang
Clever man	badāra	Younger sister	landhakaiang
Guardian of novice	bullu-wrung	Father	babang
Sorcerer	mullamulliñ	Father's father	wĕn'-tuin
Small boy	lity	Mother	yuggan
Elder brother	gandhang	Spirit or ghost	birrabang
Younger brother	bāmun	Master	munggan[1]

Parts of the Body.

Head	duduk	Shoulder	kutthak
Forehead	ngirrame	Elbow	dyilmbat
Hair of head	mundyugan	Hand	bretch or brety
Beard	yerrañ	Thigh	thurrin
Eye	mring	Shin	gurrat
Nose	gung	Knee	bun
Throat	dhuluty	Foot	dyinnang
Back of neck	nainindya	Heel	murung
Ear	wring	Sinew of heel	ngurrang
Mouth	dhang	Blood	gruk
Lips	yandang	Fat	kullunga
Teeth	ngurndak	Bone	kurraduk
Breast, female	bāk	Penis	dhun
Navel	nyuranyurin	Scrotum	dhurt
Afterbirth	wandurung	Vulva	dhallung

[1] This term, *munggan*, is applied to any elderly man who is in command for the time being, whether in a family circle, a hunting excursion, a corroboree, a ceremonial gathering, and so on.

Belly	buluñ	Copulation	thabundyan
Heart	yukarang	Semen	barringunna
Tongue	thaliñ	Urine	wirrakin
Liver	bŏthunna	Excrement	gunungunna
Arm	nhurung	Venereal	wadyuwadyung

Natural Objects.

Sun	nau-iñ	Darkness	bunban
Moon	yedding	Cold	mŭrbak
Stars	dyuang	Camp	bang
Pleiades	mamangalang	Fire	mretch
Thunder	mirribi	Smoke	dhumbak
Lightning	mallupkan	Flesh (food)	dyăk
Rain	dhau-ak	Day	nau-indyan
Fog	kanggut	Night	bunman
Frost	dhăn	Morning	dyibulagambu
Snow	dhulwurung	Evening	warinman
Hail	tuta	Leaves of trees	bulandyŭnga
Water	yarn	Flowers of trees	gŏrna
The ground	wrŭk	Wild honey	goang'gal
Mud	nyullung	Pathway	bilbukye
Stone	ngurran	Tail of animal	wirruk
Sand	wuddyat	Shadow	mambarung
A hill	bŏbal	Grass	nalluk
Mountain	mărru	Songs for dances	gŭnyaru
Light	makanau-in		

Mammals.

Native-bear	ngurka	Flying squirrel, small	waikang.
Dog	bañ	Ringtail opossum	balgai
Whiteman's dog	wandaial	Kangaroo	burru
Opossum	gungarang	Wallaroo	wandur
Kangaroo-rat	dyimmang	Platypus	gamallang
Native-cat	gunumburung	Porcupine	diddidi
Tiger-cat	gundurung	Water-rat	batbu
Rockwallaby	waiat	Wombat	bunggadhang
Flying squirrel, large	wanda	Bandicoot, long nose	mandu
Flying squirrel, medium	ngat-ngat	Bandicoot, short nose	manyuk

Birds.

Crow	marrangan	Mopoke	gogok
Laughing jackass	gwak	Bronze wing pigeon	gang-gang
Curlew	gwan-gwan	Rosella parrot	duñ
Willy-wagtail	mumanggalang	Common hawk	barakalgal
Swan	gunyak	Plover	birran-dhurran-dhurran
Eagle hawk	mirrung	White cockatoo	brăk
Emu[1]	mai-au-ra	Black cockatoo	nenak
Magpie	guramagang	Black crestless cockatoo	yaiak
Black jay	wĕbuk	Lyre bird	bullit-bullit
Black duck	bundyerrung		

[1] Also called gŭngwan-gŭngwan, from its call.

Fishes and Reptiles.

Mullet	burbiañ	Turtle	ngeth
Eel	galkun	Sleepy lizard	dyirri-dyirritch
Bream	kain	Black lizard	gurgurwurak
Trout	mŭndya	Black snake	gun'umbra
Frog	dhirragaratch	Brown snake	buli-buli
Tree iguana	dhurrang	Tiger snake	kugugun

Invertebrates.

Centipede	maral	Jumper ant	bŭl-bŭl
Mosquito	mingalin	Louse	nu-itch
Mussel	bindhagañ	Nit of louse	tŭrta
Leech	dhillang	Blow-fly	bŭmba
Bulldog ant	dyŭng	House-fly	gunadada

Trees and Plants.

A squeaking tree	gudabin	Snow gum	warrugang
Ti-tree	dyerad'deru	Sally	bubugu
Stringybark	brungal	Peppermint	dyārang
Wattle	gun'unggur	Messmate	brēak
Ironbark	burrai	Yam	milañ
Cherry tree	murrage	Ferns	war-we
White gum tree	balluk	Mushroom	gillŭn
Ribbon gum	dyua	Reed	yerka
Mountain ash	dhuru		

Weapons, Ornaments, etc.

Tomahawk	kuyan	Headband	dyalbatch
Yam stick	dhatch	Armbands	bibŭrru
Wood spear	bŭrañ	Waist belt	dhuranggal
Reed spear	dhallandyil	Man's apron	burrañ
Spear lever	murriwan	Nose peg	gumburt
Bullroarer	tŭrndun	Woman's apron	dyabañ
Boomerang	băgur	Net bag	pattyung
Spear shield	birkumba	Doctor's bag	guragang
Waddy shield	mŭrkang	Necklace	takawe
Fighting club	gudyurung	Canoe	guladung
Hunting club	bŭndi	Paddle	gulamban

Adjectives.

Alive	murulman	Slow	waddiakan
Dead	yuragat	Deaf	ngulla-wring
Large	barraude	Blind	ngulla mring
Small	ngullaburi	Strong	ngarrandyil
Tall or long	warkadi	Afraid	dyiran
Short	wombadya	Tired	durandyagat
Good	linya	Cold	mabuklani
Bad	ngallen	Angry	yerkaman
Hungry	miran	Sleepy	burumi
Thirsty	kyan[1]	Glad	yallakani
Red	kugugun	Sorry	yugani
Black	gurumbura	Greedy	nganggalak
White	tarbandrung	Sick	murugani
Jealous	yukañ	Stinking	yugganman
Lame	kŭkadik	Pregnant	wattandyil
Empty	ngadyan	Hollow	ngunguyang
Full	bulitban	Narrow	ngallaburri
Quick	yangadyan		

[1] Pronounced in one syllable.

Verbs.

Eat	dhalane	Breathe	bimbani
Drink	nungblane	Climb	warkbani
Sleep or rest	beandani	Dance	mundadyan
Stand	thetyani	Dive	mirp-gadyan
Sit	nyani	Conceal	nutyu'kan
Talk	dhanggarani	Jump	wambani
Tell	dhŭngani	Step over	wandhani
Walk	yangadyan	Laugh	tyat-yu-a-lad-yan
Run	bingadyan	Scratch	walagaladyan
Chase	murunggani	Forget	wandaguni
Bring	wanggadyan	Stare at	gaiatguni
Take	wanyandab'ila	Send	bindarin
Pick up	manganni	Shine	dakbatch
Throw down	kalak-tyukan	Suck	thālan
Break	kalakatch	Scold	yakbani
Beat or kill	bundani	Swim	banggadyan
Fight	bundaiakan	Search for	ngunladyan
Arise	bingadyan	Spit	dyuk-bladyan
Fall down	bubbagadyan	Smell	bunbuladyan
See	dhakani	Throw	wandyiggane
Hear	wanggani	Roast	gubaladyan
Give	yukananga	Whistle	wingadyan
Sing	watbuladyan	Pretend	gatbaladyan
Weep	nu-adyan	Vomit	kronggadyan
Cook	gubanyan	Sting	bundadyan
Steal	wirrunggani	Call	kandadyan
Ask	watbani		

APPENDIX.

Language of the Kurnai Tribe.

In a monograph published in 1902[1] I submitted an elementary grammar of the Gūnggaladhang, the language spoken by the Kurnai tribe, whose country is situated to the west of and adjoining that of the Birdhawal. In the paper referred to, the examples given in the pronouns and verbs were very much abridged, owing to exigencies of space, and therefore I am now desirous of supplementing what was then published, being the result of further investigations made by myself among the natives. If this additional information be read in conjunction with my memoir of five years ago, and the vocabulary of 300 words which accompanied it, the whole will then exhibit an outline of the grammar of the Gūnggaladhang tongue.

While many of the words of the Gūnggaladhang are nearly the same as those of the Birdhawal, there are a large number which are altogether different. The closest agreement is found among the pronouns and some of the verbs.

[1] *Journ. Roy. Soc. N. S. Wales,* XXXVII, pp. 92–106.

Pronouns.

The following additional examples are now supplied

Dual	First person	We, inclusive,	Ngallu
		We, exclusive,	Ngallang
Plural	First person	We, inclusive,	Ngangan
		We, exclusive,	Ngangannang

There are also forms for the second and third persons in all the numbers. The full forms of the pronouns given in this and the original table are employed chiefly in answering questions. In ordinary conversation the natives use the pronominal suffixes illustrated under the heading of Verbs.

Verbs.

In my former memoir, already quoted, in the second example of the inflection of verbs, at page 95, the *past* tense of the verb *dhakani*, "to see," was inadvertently set down as the *present*. I therefore wish to expunge lines 19 to 21 inclusive on page 95, and substitute the following fuller details of another verb, *dhanggani*, "to speak," in their stead:—

Indicative Mood—Present Tense.

Singular	First person,	I speak,	**Dhangganetch**
	Second person,	Thou speakest,	**Dhanggandu**
	Third Person,	He speaks	**Dhangga**

Past Tense.

Singular	First person,	I spoke	**Dhanggandha**
	Second person,	Thou spokest	**Dhangganinna**
	Third Person,	He spoke,	**Dhanggañ**

Future Tense.

Singular	First person,	I shall speak,	**Dhangginga**
	Second person,	Thou shalt speak,	**Dhangginnin**
	Third Person,	He shall speak	**Dhanggiñ**

Dual	First Person	We, inclusive, shall speak,	**Dhangginyal**
		We, exclusive, shall speak,	**Dhangginyallung**
Plural	First Person	We, inclusive, shall speak,	**Dhanggingan**
		We, exclusive, shall speak,	**Dhanggingannang**

Imperative Mood.

Speak!	Dhanggin!

REFLEXIVE.

I am speaking to myself,	Dhanggattharanetch

RECIPROCAL.

We, dual, speak to each other,	Dhanggaiadyalliang
We, plural, speak to each other,	Dhanggaiagundhiang

Stated Meeting October 18, 1907.

President SMITH in the Chair.

PROF. HENRY H. DONALDSON read a paper on "The Growth of the Albino Rat as Compared with the Growth of Man," which was discussed by Professors Houston and Conklin.

Stated Meeting November 1, 1907.

President SMITH in the Chair.

PROF. HOUSTON presented a verbal communication deprecating the use of the word "Aerogram" and discussed the use of other terms applied in this connection. He favored the terms "Hertzian or Marconic Telegraphy" and "Marconigram."

Stated Meeting November 15, 1907.

President SMITH in the Chair.

The following papers were read:

"Pastorius," by PROFESSOR M. D. LEARNED, which was discussed by Mr. H. La Barre Jayne.

"The New Theory of Earthquakes and Mountain Formation, as Illustrated by Processes Now at Work in the Depths of the Sea," by PROF. T. J. J. SEE. (See page 369.)

Stated Meeting December 6, 1907.

President SMITH in the Chair.

The decease was announced of Prof. Asaph Hall, at Annapolis, Maryland, on November 23, 1907, æt. 78.

The following papers were read:

"The Treatment of Mental and Moral Retardation," by PROFESSOR LIGHTNER WITMER, which was discussed by Mr. Sachse, Prof. Jastrow, Mr. Goodwin and the President.

"The Languages of Some Tribes of Western Australia," by PROFESSOR R. H. MATTHEWS. (See page 361.)

Stated Meeting December 20, 1907.

President SMITH in the Chair.

The list of donations to the library was laid on the table and thanks were ordered for them.

The decease was announced of The Right Hon. Sir William Thomson, Lord Kelvin of Largs, at Largs, Scotland, on December 17, æt. 83.

PROF. LEWIS M. HAUPT read a paper entitled "The History of Aransas Pass to Date."

The president delivered the "Annual Address."

LANGUAGES OF SOME TRIBES OF WESTERN AUSTRALIA.

By R. H. MATHEWS, L.S.

(Read December 6, 1907.)

For the last eight years I have been endeavoring to obtain original information respecting the sociology, language, folklore and customs generally of the aborigines of Western Australia. Early in 1900 I had the matter sufficiently developed to publish the sociology of the tribes on the sources of the Ord, Fitzroy and Margaret rivers in the Kimberley district.[1] Towards the end of the same year I published a map showing the distribution of various tribes possessing different types of sociology throughout nearly the whole of Western Australia.[2]

In 1901 I gave further details of the sociology as well as a vocabulary of one hundred and eighteen words of the language spoken in the Kimberley district.[3] In 1903 I described some interesting rock paintings and carvings, and supplied vocabularies of the languages of the natives at Roebourne and on the Lower Fitzroy river.[4] During 1907 I further illustrated the sociology of the tribes between Albany and Perth, and also that of the Erlistoun tribe.[5] Some of the folklore and customs of the aborigines of Western Australia are now in course of publication by me elsewhere.

In the present monograph I shall briefly deal with the language of some tribes occupying the country approximately from Laverton and Weld Spring eastward to the boundary of South Australia, and extending into the territory of that state for about two hundred miles. The total length of this tract of country may be stated as approximately six hundred and fifty miles and its breadth three hundred miles. Each tribe is treated under a separate heading.

[1] *American Anthropologist,* N. S., pp. 185–187.

[2] *Proc. Amer. Philos. Soc., Phila.,* xxxix, pp. 89, 123–125, 560–575, with map.

[3] *Journ. Roy. Soc. N. S. Wales,* xxxv, pp. 217–222.

[4] *Queensland Geographical Journal,* xix, pp. 45–72.

[5] *Ibid.,* xxii, 1907.

The Loritya Tribe.

is located on both sides of the boundary between West- ... and South Australia. Its territory is approximately ...h range northerly to Lake Macdonald, including the Tom- ...an Petermann ranges, and reaching into Western Australia ... e distance. It also extends into South Australia to the ... e ...nges, Lake Amadeus, and the Ehrenberg ranges.

...grammatical structure of the Loritya language is substan- ...ly the same as ...at of the ...n natives on the Swan river. The no... pronouns, verbs and other parts of speech are declined in an analogous manner, and some words of their vocabularies are almost identical. The Loritya grammar is also the same in principle as that of the Arranda language, reported by me in the *Proceedings* (see page 322).

Nouns.

Nouns have number, gender and case.

Number.—There are the singular, dual and plural numbers, which are declined by postfixes; thus, kalaia, an emu; kalaiatara, a pair of emus; kalaiakura, several or many emus.

Gender.—Sex in the human family is distinguished by different words, as: patu, a man; kunka, a woman. For the lower animals, gender is indicated by the addition of the word manti for males and yakura for females. The ordinary native terms for "father" and "mother" are often employed for the same purpose.

Case.—Examples of the nominative, causative, genitive, and instrumental will be given, but there are likewise forms for the dative and ablative. The accusative is generally the same as the nominative.

The nominative indicates anything at rest and is without flexion, as: patu, a man; kunka, a woman; wonna, a yamstick.

Causative: This is used for any action described in a transitive verb, and takes the suffix *nku,* as: paturku waru pungu, a man a rock-wallaby killed.

The instrumental case takes the same suffix as the causative, as: kunkanku inalingi wonnanku pungu, a woman a porcupine with a yamstick killed.

Genitive: This case is formed by adding *ku* to the nominative, as: meru partuku, the womera of the man, or a man's womera; wonna kunkaku, a woman's yamstick.

Adjectives.

Adjectives follow the nouns which they qualify and are subject to the same inflexions. Comparison is effected by means of two positive statements, such as: this is good—that is bad. In the declensions of all the cases of nouns, and of their qualifying adjectives, there are modifications in the affixes, depending upon the termination of the word declined. Sometimes the affix of the noun is omitted, sometimes that of the adjective, this matter being regulated by the euphony of the sentence.

Pronouns.

Pronouns are inflected for number, person and case, and contain two forms of the first person in the dual and plural, marked "inclusive" and "exclusive" respectively in the following tables. The nominative pronouns are given in full.

Singular	1st Person	I	Ngaiulu
	2d Person	Thou	Nuntu
	3d Person	He	Paluru
Dual	1st Person	We, inclusive	Nuntungali
		We, exclusive	Ngali
	2d Person	You	Numbali
	3d Person	They	Palumkutara
Plural	1st Person	We, inclusive	Nguntunganana
		We, exclusive	Nganana
	2d Person	You	Ngurangari
	3d Person	They	Tana

The possessive pronouns are as under:

Singular	1st Person	Mine	Ngaiuku
	2d Person	Thine	Nuntuba
	3d Person	His	Palumba
Dual	1st Person	Ours, inclusive	Nuntungalimba
		Ours, exclusive	Ngalimba
	2d Person	Yours	Numbalimba
	3d Person	Theirs	Palumbakutara
Plural	1st Person	Ours, inclusive	Nuntunganamba
		Ours, exclusive	Nganamba
	2d Person	Yours	Ngurangarimba
	3d Person	Theirs	Tanamba

I am not yet in receipt of sufficiently definite information to furnish details of the remaining parts of the Loritya grammar, but the subject will receive further attention in the near future.

The Erlistoun Tribe.

I have not been able to obtain the name of the tribe occupying the country between Menzies and Lake Wells, including Erlistoun, Laverton, Duketon and other places in the Mount Margaret gold field. This tract may be approximately defined as being situated between the 27th and 29th parallels of latitude, intercepted between the 121st and 125th meridians of longitude. I have provisionally adopted the name of the Erlistoun tribe for the aborigines of this region for purposes of reference. The center of the tract of country indicated is approximately four hundred and fifty miles west of the western boundary of South Australia, and about the same distance northeast of Perth, the capital of Western Australia; in other words, about half way between Perth and the Petermann range on the boundary between the two states mentioned.

Any information, therefore, which we can collect and promulgate respecting the language of a tribe so situated must be of the highest value to the ethnologist, being a connecting link between the speech of the natives of Perth and those occupying the region on both sides of the boundary between Western Australia and the neighboring state of South Australia.

I have not yet succeeded in completing a grammar of the language spoken by the natives of the Erlistoun district, but I have been fortunate enough to find a competent and reliable resident of that part of the country, who has supplied me with a vocabulary of one hundred and three words taken down by himself from the lips of old blacks of both sexes, who were well known to him, and upon whom he could depend.

If we compare the vocabularies of the Erlistoun and the Loritya, printed side by side at the end of this monograph, we discover that thirty of the words are the same or practically the same, whilst eight others are very similar. That is to say, more than a third of the Erlistoun words are substantially the same as the corresponding words in the Loritya. I may state that my correspondent was altogether unacquainted with the Loritya dialect, and none of the natives of that tribe were within hundreds of miles of his home at Duketon. There was therefore no possibility of his inadvertently mixing the words of both tribes.

Then, if we compare the Erlistoun vocabulary with the one published by Sir George Grey in 1839 of the Perth language, we find that eleven of the words are the same and that six are closely similar. In 1903 I published a vocabulary of the dialect spoken at Roebourne, taken down by myself from a black fellow belonging to that portion of Western Australia. In comparing that vocabulary with the Erlistoun, six hundred miles distant, we notice that seven of the words are the same and two similar. These agreements in several words of the vocabularies of tribes separated from each other by many hundreds of miles point to a common origin of the speech of the people over a very large geographic area.

Vocabulary.

The following vocabulary contains 127 words of the Loritya language and 103 of the Erlistoun. The words of a similar character are grouped together under separate headings instead of being arranged in alphabetical sequence.

It may be explained here that I sent the same category of English words to both my Loritya and Erlistoun correspondents, which enables us to make a ready comparison. In the case of my Roebourne vocabulary of 1903, referred to in an earlier page, I had a more or less different list of English words for which to obtain equivalents. This remark applies also to Sir George Grey's vocabulary. It is probable that if we were to go to Roebourne or Perth with the list of words contained in the attached vocabulary and interview the natives, the identity or resemblance of many more words could be established than we can see in the present list.

For the Loritya grammar and vocabulary I am indebted to Mr. C. F. T. Strehlow, who has known the tribe for several years. The vocabulary and other particulars of the Erlistoun natives were supplied by Mr. Kenneth Young. Both these men have been in correspondence with me for some time and I can rely upon their information, which was obtained direct from the aborigines.

English.	*Loritya.*	*Erlistoun.*
Mankind	Matu	Wongada
A man	Patu	bundhu
Father	katu	mummali

Elder brother	kuta	kudrolli
Younger brother	malunga	murlunga
Boy	ula	murdilla
Doctor	nangari	
Woman	kunka	nunga
Mother	yako	yaggoli
Elder sister	kangura	ludrolli
Younger sister	malangu	murlungu
Girl	kuyuna	tunguna
Infant	pipiri	diddi
Mother-in-law	wumaru	

THE HUMAN BODY, ETC.

Head	kata	kuddya
Eyes	kuru	guru
Nose	mula	mula
Tongue	talinya	mullin or midang
Teeth	kadidi	kardidi
Ears	pina	guran
Hand	mara	murra
Elbow	nguku	bŏrk
Shoulder		birri-birri
Foot	tyina	dyinna
Knee	mardi	murdi
Blood	ngurka	guyul
Fat	niti	nirdi
Bone	tarka	durga
Penis	kalu	wiba and wilo
Vagina	tyuka	nungna
Anus	kunnatan	buna
Excrement	kunna	guna
Urine	kumbu	

INANIMATE NATURE.

Sun	tyintu	tyindu
Moon	pira	kulga
Stars	tyil-tyana	mullai
Fire	waru	worro
Charcoal		yirriga
Smoke	buyu	buya
Water	kape	gabbi
Rain	ir-tyingi	tuda
Rainbow	kanturangu	yu-aro
Spring of water		tu-lu-o
Camp		ngura
The ground	manta	burna
Sand	karu	birria
A stone	buli	
Rock	walu	
Hill	puli-urta	
Pipe-clay	ikuna	tunba
Red ochre	ulba mapanu	murda

ANIMALS.

Opossum	waiyuta	waiada
Porcupine	inalingi	mingarri
Rock wallaby	waru	dyi-waigu
Euro	kanala	kulthalla

Red kangaroo	malu	
Bat	ulbulbine	mun-dyar
Dog	papa	wongu
Emu	kalaia	kullaia
Eaglehawk	katuwara	dedo
Pelican	kabilyalku	
Crow	kanka	karn-ga
Common magpie	urari	
Jay magpie	aputan-tyen-tyi	
Pee-wee	kurbaru	kudbaro
Curlew	wilu	
Owl	wiratu	
Iguana	wongapa	kud-bardai
Brown snake	maru-marura	liro
Carpet snake		mullawanna
Mussel	pira-pira	
Mosquito	kewinye	kumminga
Centipede	kanbarka	
Louse	kulu	win-ga

Trees and Plants.

Red gum tree	itara	
White gum tree		yarda
Grass tree	ulunkuru	
Beefwood	il-tyan-tyi	
Desert oak	irgapa	
Cork tree		buruga
Narrow-leaf mulga		guya
Black mulga		win-dyal-ga
Honeysuckle		yurabuddi
Turpentine bush		giddi
Spinifex	untia[1]	bilya and tyan-bi
Bullrushes	unka	
Grass	puta	

Implements, Utensils, Etc.

Stone tomahawk	ilipi	yilgun
Stone knife	tula and irkili	gun-dyi
Spear	katyi	kar-dyi
Shield	ku-ti-tyi	tarro
Womera	meru	mirio
Boomerang	kali	birridi and wallanu
Club	kunti	kundi
Yamstick	wonna	yan-dya
Lower millstone	tyu-a	kuro
Upper millstone	miri	
Trough, wooden	kuntili	wiria
Girdle	nanpa	nanbar
Apron	matati	gun-dya
Nose-peg	unati	mu-le-iddi
Bullroarer	wunninge	

Adjectives.

Large	buntu	gunanna
Small	wima	tuguni
Straight	tukururu	tugarraru
Crooked	kalikali	grin-grin

[1] There are two sorts of spinifex, one of which grows on the sandhills, and the other on rocky ground The natives have names for both.

Good	pala	
Bad	kuya	
Hot	aranta	bubbarra
Cold	warri	yalda
Hungry	a-in-ma	
Tired	burka	nuria
Greedy	waiangulkunmi	
Stinking	boka	yuna
Thirsty		tan-dyarra

Verbs.

Stand	ngarange	ngarrago
Sit	ninanye	illago
Walk or go	yenanye	thulgargo
Run	talkalunganye	tinyarn
Eat	ngalkunye	nannago
Drink	tyi-kinyi	bubbago
See	nanganye	dargo
Hear	kulinye	kurilgo
Chop	mutunye	
Bite	patanye	
Talk	wonkanye	wongi
Laugh	inkanye	ēgarri
Beat	bunganye	bungugo
Give	yunganye	
Throw	runkanye	
Carry	katinye	
Pick up	mungaratalkanye	mangugo
Throw away	wonniriyenanye	wonnigo
Steal	mulatanka manyinye	woggalgo

Numerals,

One	kuta	Not obtained.
Two	kutara	
Several	mankura	

Adverbs.

Yes	o-wa	Not obtained.
No	we-ya	

Correction.

In volume XXXVIII of this journal, page 77, table II, then publishing the eight intermarrying sections of the Warramonga tribe at Tennant's Creek, N[illegible] I regret that some errors crept in during [illegible] the section names from one of my previ[illegible]ave published several correct tabl[illegible]er the reader to one of them, [illegible] Vol. XXVIII, pp. 87 seq., table [illegible] the intermarrying laws in force

R. H. Mathews.

THE NEW THEORY OF EARTHQUAKES AND MOUNTAIN FORMATION, AS ILLUSTRATED BY PROCESSES NOW AT WORK IN THE DEPTHS OF THE SEA.

(With Maps I.–III.)

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(*Read November 15, 1907.*)

I. On Earthquake Processes Observed in the Depths of the Sea.

§ 1. *General Considerations.*—In two previous papers dealing respectively with the "Cause of Earthquakes" and the "Temperature of the Earth," a new theory has been developed which unites and harmonizes the most varied phenomena connected with the physics of the earth. These papers present the theory in a way which will no doubt seem convincing to the careful reader who has adequate experience in the physical sciences. But even the lay reader is entitled to all the light which may be shed on this difficult subject, and as the departure from previous theories is somewhat radical, it has seemed advisable to record some additional considerations which may be of interest also to the professional student of science.

This course seems the more appropriate in view of the established habits of thought of contemporary investigators, some of whom will naturally welcome any step which will simplify our understanding of physical phenomena. As the subject is extensive and complex and presented under various aspects in the different sciences, a connected view of the laws operating in the development of the earth's crust is by no means easy; for, if it were, the underlying cause no doubt would have been discovered long ago, and great improvements already would have been made in many of the physical sciences which deal with the terrestrial globe.

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only $1:(10)^n$, where we may put $n=33$. Thus the chances are only one in a decillion that this geometric parallelism would occur without a common underlying physical cause. The coincidence in volume is even more improbable, so that the agreement in direction and in volume, if depending wholly on accidental coincidence, would have a chance of only $1:(10)^{66}$, or one in a decillion decillions. A decillion decillions is practically an infinite number; and it therefore follows that the coincidence in direction and in volume depends on a true physical cause connecting the elevation of the range with the adjacent depression in the sea bottom.

Moreover, after great earthquakes in this region, new islands are frequently raised from the sea, and several new volcanoes have broken out within historical time. Seismic sea waves of the first class frequently follow, the water first withdrawing from the range of islands towards the trough to the south, and then returning later as a great wave. This shows that the sea bottom to the south sinks after the earthquakes by which the region is afflicted. As the islands, and in fact the whole mass of submarine mountains are uplifted by the disturbance, and the sea bottom afterwards sinks, it is evident that lava is expelled from beneath the trough and pushed under the adjacent range. The bed of the sea then gives down to fill up the partial cavity from which the molten rock has been expelled. It will be noticed, moreover, that the trough lies between the ocean and the mountain range, and hence if the leakage of the ocean were the cause of the expulsion of the lava, the subterranean movement necessarily would be towards the mountain range, in accordance with observation.

From this remarkable series of concurrent phenomena, it follows that the chances are literally infinity to one that the trough and ridge are physically connected. It thus becomes an absolute certainty that the submarine mountain range is formed by the expulsion of lava from beneath the trough, that the whole movement is due to the leakage of the ocean, and that it is going on right now; so that the effects observed within historical time are seen to be but a part of the secular process which has crumpled the earth's crust in this complicated manner.

A study of the map of North America shows that the Alaskan mountains to the north of Cook's Inlet are merely a continuation of the Rocky Mountains of Canada and the United States. The Alaskan mountains form the back bone of the Alaskan peninsula and continue into the sea as the Aleutian Islands. The Aleutian Islands are therefore part of the Rocky Mountains still beneath the ocean to show us how the whole system was formed in the course of immeasurable ages. What is here said about the Alaskan mountains running into the sea applies equally well to various other chains of mountains in different parts of the world.

Thus Mr. Caspar Wistar, formerly a student of Professor E. W. Brown, at Haverford College, now at Temuco, Chile, in sending the writer some valuable observations on the Andes, says: "The coast range begins properly about 25 miles north of Santiago, and there is no trouble in following it until it finally disappears in the ocean in Tierra del Fuego and Cape Horn. Lying between the coast range and the Andes is the central valley of Chile. At the northern end is the highest part, where it is close to 2000 feet above sea level; this gradually grows less as one goes south until finally at Puerta Montt it enters the ocean and can be followed on south below the sea level to Smyth's Channel and the western part of the Straits of Magellan."

In like manner the mountains of the peninsula of Lower California are continued under the sea; and dozens of other cases could be cited. These need not be dwelt upon here, as they are already sufficiently familiar to the reader. The case of the Aleutian Islands has been chosen for detailed study, because the mountain forming process is still actively at work there in a way which shows its real character.

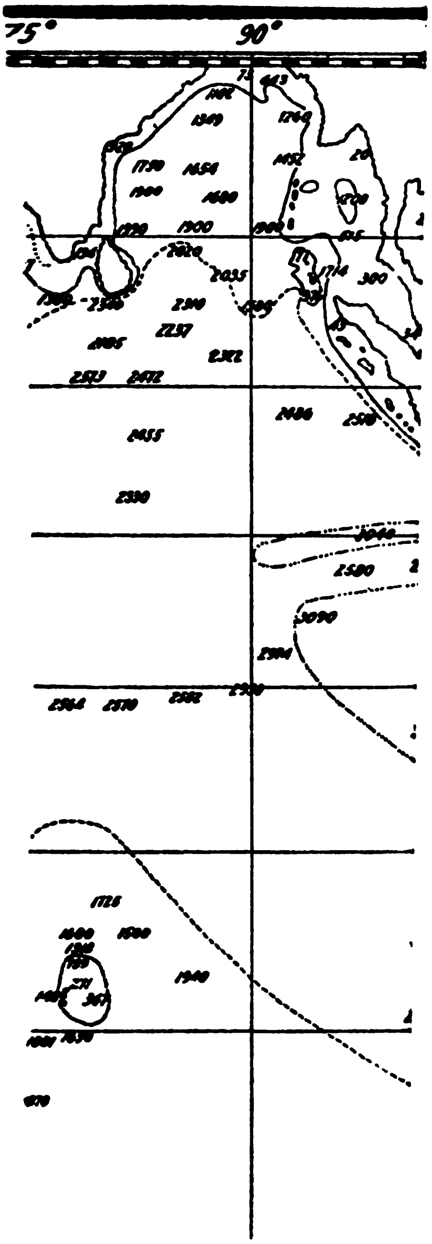
The true process by which mountains are formed near the margin of the sea is thus recognized and placed beyond all doubt. Accordingly it follows that the old theories of mountain formation must be entirely abandoned, as having no valid foundation in nature. For owing to the similarity of the effects we cannot suppose that some mountains are formed by one process and some by another. All mountain ranges were near the sea originally, and essentially parallel to the shore; and since the mountains rear their lofty summits

a. [...]ted walls around the land, it follows incon-[...]ntains of the globe depend on the same cause, i[...]han the secular leakage of the ocean bottoms. [...] to that here employed could be extended to [...]r the Kurile and Japanese Islands; and by the [...] the ocean depths throughout the world one [...]ly what the state of seismic activity is in any [...] such digging out of troughs and elevation of [...]ound to be going on within any continent, and [...] it follows that all mountain ranges have been formed by the sea and not at all by the shr[...]globe, which obviously is cooling as much in the desert [...]ng the sea coasts.

§ 3. *Application of this Th[...]ticular Regions of the Ocean Bottom.*—In view of what [...]aid above regarding the uplifting of ranges in the sea, is it an[...]er that volcanoes should break out in the Aleutian Islands? Or, [...] Major Dutton remarks, that the Russians should connect the ea[...]uakes with the volcanoes of this region? The connection is now established beyond all controversy, and it is shown that the earthquakes are the cause both of the volcanoes and of the mountain formation now going on in the Aleutian Islands.

In Japan the very same cause is at work, and the whole island Empire has been uplifted from the depths of the sea by the injection of lava expelled from beneath the bed of the Tuscarora Deep, which has thus sunk down and developed into the greatest abyss in the world. The true cause of the earthquakes and sea waves by which Japan is afflicted lies in the depth of the ocean to the east of these islands and the resulting leakage and expulsion of lava from beneath it. As the ocean is deepening all the time, this region will always be greatly afflicted by seismic disturbances, and the Japanese people must adapt themselves to the nature of their unstable country, which is still emerging from the depths of the ocean.

It is easy to apply this same reasoning to the East Indies, and hence we see why Java, Sumatra, and other neighboring islands are so afflicted by earthquakes, volcanoes, and seismic sea waves. This region probably is in a more advanced stage of development



COAST SURVEY MAP OF THE REGION O
the continuous dashes 2000 fathoms, and th

than that of the Aleutian Islands. The latter will eventually connect North America with Asia, and the Arctic will be entirely cut off from the Pacific Ocean. Thus by the study of maps of the ocean depths much light can be thrown upon the past history and present tendencies of the surface of our globe. Even now we may see the formation of islands, mountains and borders of continents still going on. Not only is mountain formation and the uplift of islands going on near the margins of the sea, but, also, at considerable distance from the continents, towards the interior of certain oceans. As a good illustration of this interior development we choose the region of the Friendly Islands in the Pacific between Samoa and New Zealand. Here the water is very deep and the narrow trench is built exactly like that near the Aleutian Islands, having on the west a ridge which has been uplifted by the injection of lava from beneath the trough to the east. The Pacific is here developing a long mountain wall on the west, and it will eventually connect Samoa with New Zealand. The earthquakes and seismic sea waves observed in this region show that the process is going on now, and slowly developing a chain of mountains in the open sea, at some distance from any large continent.

§ 4. *On the Development of Islands and Island Chains.*—In view of the above considerations, it is clear that small islands are essentially mountains under water; and that in the case of large islands the uplifted area was larger, and the bases have since been broadened by the elevation of more land, and the tops flattened by the agencies of wind and water. This was pointed out in the first paper on the cause of earthquakes, §§ 30–38, and attention was called to the lay of the mountains along the centers of the islands, and to the depressions in the bed of the ocean near many of them, due to the sinking of the sea bottom, after the crust was undermined in the process of elevation. By a continuation of the process almost any amount of land could be added. When the uplifted area is of considerable extent, the resulting islands are large, and have flat tops, partly owing to the secular effects of such agencies as wind, water and the leveling action of the waves. Whenever we see a chain of islands in the sea, we know that they are essentially the peaks of a moun-

tain range elevated above the water. A case such as that offered by the Aleutian Islands proves this beyond all doubt; yet in most cases the process of formation has been slow, and the present state of the sea bottom does not show exactly how the development came about. From the study of those islands near which depressions exist we may in time gather much light on the details of island development, and in this way add to our knowledge of the geology of the sea. While the illustrations already given show the general nature of the process, it is clear that the sea bottom is still too little explored to enable us to treat of all cases intelligently, and we must therefore wait for more light as the surveys of the oceans are gradually extended. It is obvious that exact surveys of the sea bottom are needed not only for the laying of cables, but also for the study of the earth's geological history; and the time may come when exact ocean surveys may be as important for our knowledge of the physics of the earth as geological or geodetic surveys of the land.

§ 5. *On the Nature of the Molten Rock Which Moves Beneath the Earth's Crust.*—In the paper on the Cause of Earthquakes we have pointed out the leaky character of the earth's crust, and shown how steam will naturally form in the hot rocks beneath till the lava becomes so fully saturated by this vapor that it swells and requires more space. The steam is not held to be free, but absorbed in the hot rock, causing it finally to expand till it becomes irresistible; and when the elastic tension of this steam-saturated lava becomes great enough the crust begins to shake and the paroxysm continues till it moves along the nearest fault line. When the underlying molten rock has thus obtained more space, the agitation ceases till the tension again becomes too powerful for the crust to withstand, when another readjustment will take place. Thus the process is repeated at successive somewhat irregular intervals of time. The shaking is due to the enforced movement of the molten rock beneath the crust, and the paroxysm thus developed sometimes shakes down cities and devastates whole countries.

A familiar illustration of this process is seen in the lid of a tea-kettle when the steam pressure accumulates till it sets the lid quivering; as the steam escapes at the sides the agitation slowly dies down,

and the lid then remains quiescent till the accumulating pressure again requires relief, when the shaking is renewed. Thus the process is periodic, and the period depends on the rapidity with which the steam is developed. In the case of earthquakes, as already remarked, the steam is not free, but absorbed in the molten rock, and when the agitation begins this gives a similar quivering motion to the block of the earth's crust overlying it, and ceases only when readjustment occurs, usually by the neighboring fault slipping in some way to give more space to the swelling lava beneath. The period is not so regular, as in the case of the tea-kettle, because the resistance to be overcome is never the same in two successive earthquakes; nor is an equal amount of relief afforded even when the underlying force is identical, because the crust moves as soon as its resistance is overcome, and it ceases to move when the displacement is sufficient to restore equilibrium. As the resistances to the blocks of the earth's crust are constantly varying, owing to their complicated mutual relations, and the steam also accumulates at various rates and unequally under different parts, the intervals between successive shocks may be approximately, but are never exactly, equal. Settlements after great shocks, and slight stresses, are relieved by small movements, but eventually the tension becomes great enough to demand a displacement that will provide more space beneath the crust, and then the resulting fault movement usually is conspicuous enough to show at the surface of the ground. The crust is about fifteen or twenty miles thick, and molten lava seldom reaches the surface, except when the crust is uplifted and an outlet facilitated by the opening of cracks, as in mountain chains, which may be along the shore, or in the depths of the sea, projecting above the water as islands. Hence not all islands are volcanic; and by no means all mountains become volcanoes; but such outbreaks frequently happen in the neighborhood of deep seas, where the expulsion from beneath the sea is most violent, and the crust is abruptly and sharply upheaved, so as to afford a chance vent for the imprisoned vapor.

§ 6. *The molten rock beneath the oceans probably experiences an enforced creep towards all available avenues of escape, but the movement usually is not rapid enough to prevent the bottom from*

sinking where the undermining due to expulsion is very active. This may be inferred from the fact that an ocean such as the Pacific is surrounded everywhere by high mountains, and often by table lands of great elevation. All these mountains and plateaus have been raised from the sea, by injections of lava expelled from beneath the bed of the ocean. The fact, however, that in many places, as along the Aleutian, Kurile, Japanese, and East Indian islands, South America, and elsewhere, the expulsion of lava has been so rapid as to dig out trenches near the ranges of mountains thus elevated, leads one to recognize that in some places the expulsion towards the land is more rapid than the creep of lava from under the sea towards the shore, so that the sea bottom sinks down into a trough. This expulsion of lava happens in a good many places, and the phenomena are clear enough to admit of no doubt. Yet it seems certain that some lava creeps under the crust towards all avenues of escape, along the paths of least resistance, and enforced movements occur in submarine earthquakes. Islands are thus raised in the sea, and where the undermining is rapid the adjacent sea bottom sinks down. Sometimes large plateaus form in the ocean, and slowly rise to the surface, so as to form a large flat island, generally of an elongated type. Submarine plateaus of this kind are now to be found in the north and south Atlantic, and elsewhere, and there can be scarcely any doubt that the leakage of the ocean finds relief by the gradual elevation of such submarine masses, as well as along the shores. The effect of this process is to augment the corrugation of the earth's crust in the course of geological time; and eventually the highest mountains in such submarine ridges rise above the water as islands. On October 16, 1907, a very powerful earthquake was felt all over the world, and the seismographic records located it in the Pacific Ocean between Mexico and Hawaii, about 1,000 miles south of San Francisco. This earthquake seems to have been purely submarine, and even more powerful than those which devastated San Francisco and Valparaiso. It is by such submarine movements that the sea bottom is constantly disturbed and corrugated and crumpled in a thousand ways, and some of the elevations are eventually lifted above the water as islands.

§ 7. *The Effects of Pressure upon the Penetration of Water into the Earth's Crust.*—To judge how effective the pressure arising from the depth of the ocean is in driving the water into the crust of the earth, we may observe first that as water is nearly incompressible for moderate pressures, the tendency to penetrate the rocks is everywhere proportional to the depth of the sea. Thus the deeper the water the greater the pressure and penetrating power. Consequently it is chiefly in the deepest water that we should expect to find the maximum effect arising from the secular leakage of the ocean bottoms. In water of any given depth the pressure is theoretically sufficient to throw a free jet to the surface, if the stream could be made to operate in a vacuum. The pressure in a sea one mile deep would thus throw a stream a mile high; in a sea two miles deep, two miles high; and so on. Now some of the ocean depths exceed five miles, the greatest, near Guam, being 5,269 fathoms, almost exactly six miles. Is it therefore any wonder that the deeps east of Japan, near the Aleutian Island, west of South America, near Guam, between Samoa and New Zealand, give rise to enormous leakage of the sea bottom, and consequently many world-shaking earthquakes? A comparatively feeble pressure of water, such as hydraulic engineers use in mining, rapidly cuts away hills and washes out all their gold; in the same way the waters of Niagara, falling through only 160 feet, slowly wear away the solid rock over which they pour.* What then may be expected of a constant water pressure which will throw a jet five miles high? Such is the pressure all over the bed of the Tuscarora Deep, and it continues from year to year, century to century. It is this pressure which forces the water so rapidly into the earth, and gives rise to all the great earthquakes and sea waves with which Japan is afflicted. No stone on earth, however thick its layers, could withstand such a pressure; nay, under it the water would go through the hardest metals, and sink down deeper and deeper into the bowels

* This analogy with the hydraulic effects of streams of water in motion is not perfect, for the water in the deep seas is merely subjected to great pressure, without bodily movement; yet in both cases the water penetrates the stone to a certain depth. In the one case the water keeps on descending into the earth, in the other the surface particles are carried away by the moving stream.

of the earth. Thus subterranean steam would arise beneath the crust and accumulate till relief was afforded by a shaking of the earth, which gave more space for the saturated underlying molten rock. Hence arise the earthquake belts near the deep seas, where easy relief becomes established in the neighboring crust as it is gradually uplifted into a great ridge or mountain chain.

§ 8. *Explanation of the Instability of Steep Slopes near Deep Seas Noticed by Seismologists.*—Montessus de Ballore and Professor Milne both dwell on the instability of steep slopes near deep seas. The meaning of this is now plain; namely, the slopes become steep by the uplifts due to the expulsion of lava from beneath the deep seas, and the seismic instability arises from this expulsion of lava under the land. The converse proposition for shallow seas is obvious enough, and well illustrated almost all over the world. In some places relief goes on after the seas have become shallow, but there can be scarcely any doubt that the movement started when the water was deeper than it is now. *The world as we find it represents the cumulative effects of physical causes working over vast periods of geological time. And our best rule is to study the typical processes where the water is deep, and the undermining and upheaval so plain as to admit of no doubt. In time we may be able to trace out the history of other unstable regions now in shallow water, or even above the sea level.* No one would now expect to see a range of mountains form far inland, and where such ranges now stand the bed of the sea once encroached. In the course of time the details in the development of such ranges will no doubt be fully worked out, but geology is not yet sufficiently advanced to unravel all that is hidden in the crumpling and folding of the earth's crust. The progress of the next two centuries ought to enable us to write a fairly accurate history of the development of the earth. All the details of particular regions now being gathered would be unintelligible unless analyzed by means of correct underlying principles, and as these have only been established very recently, we content ourselves with outlining correct general ideas, and illustrating the true physicial cause by a few cases which are beyond question. More cases can be added when our knowledge of the world is more developed; but it may require the work of several

centuries to bring out this complex development for all the principal regions of the globe.

II. Causes other than the Secular Leakage of the Ocean Bottom.

§ 9. *The presence of mountain forming processes in the sea, and the absence of such disturbances in the interior of continents excludes the consideration of secular cooling as an active cause in the modification of the earth's crust.*—In the paper on the temperature of the earth we have seen that secular cooling is a very slow and gradual process; and, moreover, it would necessarily operate as effectively for inland as along the sea coasts. Consequently if this cause were real, it ought to produce effects inland comparable to those along the edges of the continents; but the mountains are forming in the sea, and those already completed are distributed along the sea coasts; so that no one would think of ranges now being developed in an interior region far from the oceans. The absence of such mountain-forming processes in the interior of the continents therefore excludes secular cooling as an active agency in the modification of the earth's crust. *The effects of secular cooling could in no case exceed the disturbances noticed in the inland regions, and as these are insensible in regions free from water, it follows that secular cooling is not a true physical cause of mountain formation and kindred phenomena. Consequently this cause is not now and never has been active in modifying the crust of our globe.*

§ 10. *The Untenability of the Theory that World-Shaking Earthquakes Arise from the Snapping and Bending of Rocks.*—In view of what has been established in this series of papers, it is difficult to see how any one could again ascribe world-shaking earthquakes to the bending and snapping of rocks under stresses arising from the progress of secular cooling. If this is the cause which is at work, why should the great seismic disturbances occur chiefly in or near the oceans, and especially where the sea is deep, while inland regions remain quiescent? By no possible stretch of the imagination can these movements be traced to the secular cooling

of the terrestrial globe. For, if so, how are we to explain the digging out of ocean trenches and the elevation of the adjacent crust into a mountain range, as often happens in the depths of the sea? If any kind of wrinkling due to secular cooling were at work, it seems certain that the inland regions could not escape the same influence.

The difficulty experienced in accounting for the vibrations of the great earthquake at San Francisco, on the hypothesis that a rock had snapped or slipped, is thus fully sustained. If such a cause had given rise to the earthquake, the vibrations would have been of simpler character, accompanied by less rotatory motion, and the whole disturbance would have been less violent and of much shorter duration. It may be asserted with confidence that no vibrations arising from the snapping of rocks would have been sufficiently powerful or long continued to shake down cities and spread universal devastation over the land. Above all, such effects of secular cooling could not explain a general phenomenon like the uplifting of the mountains as veritable walls about the margins of the sea. Nothing but the expulsion of lava from under the sea would be adequate to account for this upheaval of the crust, and it is hard to see how any thing but the shaking incident to this enforced and prolonged subterranean movement could devastate the land and disturb the whole world. In the expulsion of lava from beneath the sea, the true cause of earthquakes is clearly recognized, and all the most important phenomena connected with the physics of the globe are correctly assigned to the secular leakage of the ocean bottoms, which necessarily is greatest where the sea is deepest. This hypothesis alone is adequate to account for all the phenomena of nature. The unity and harmony and mutual dependence shown to exist among the most diverse phenomena observed at the surface of the earth is the best proof of a common underlying cause, and such a theory will strongly commend itself to the natural philosopher who seeks in the abundance and variety of nature indications of a single fundamental law.

How great is the change in the new point of view may be seen from the following discussion by Professor J. W. Gregory, taken from the "London Sunday at Home," 1906:

"A volcano is a pin-prick in the earth's surface and it serves to relieve the local pressure by permitting the escape of steam and molten rock; but an earthquake is produced in most cases by a sudden fracture of the solid substructure of a large region, and as the great mass of material slips into a new position, the shock causes the crust of the earth to shiver from pole to pole. These dislocations are naturally most frequent in regions where mountain ranges are apparently still being squeezed up—where rocky folds are still being bent into shape, as in the Himalayas, and off the west coast of North and South America, and the North of Japan. Regions of greatest instability of the earth's crust are, in fact, found chiefly along the margins of continents or tablelands which rise suddenly to considerable heights above oceanic or other plains. Comparatively few earthquakes have their origin near to volcanoes, and the general belief that all great earthquakes are due to volcanic eruptions is not supported by evidence derived from observations."

Professor Gregory thus says that earthquakes occur chiefly where mountain formation is in progress, but he is entirely silent as to the cause of mountain formation itself. Unfortunately he blindly accepts the traditional doctrine of the secular cooling and contraction of the globe, which is shown to be devoid of any sound physical basis.

§ 11. *An Estimate of the Relationship between the Expansion and Contraction of the Globe.*—It is well known that at intervals the sea coasts are elevated by the world-shaking earthquakes to which they are subjected. It is difficult to form an estimate of the total area thus uplifted, but for a preliminary estimate we may take it to have an average extent of 200 miles square, which would about correspond to the phenomena witnessed in the greatest earthquakes. There would be 4,924, or roughly 5,000, such areas on the surface of the entire globe. According to Milne's estimate of 60 world-shaking earthquakes per annum, there would be 120,000 in the 2,000 years which have elapsed since the century before the beginning of our era.

Now an examination of great earthquakes shows that about one in four is accompanied by a sensible elevation of the disturbed area. If there are in all 5,000 such areas to raise, and 30,000 disturbances for raising them, it follows that on the average, when all areas are affected alike, each part would be raised 6 times in 2,000 years. An average raise of 2 feet is not extreme, and this gives an expansion of the total surface of the globe amounting

to 12 feet in this period. In the paper on the temperature of the earth, p. 286, we have shown that the shrinkage due to cooling in 10 million years, according to Daniell, would not exceed 612 feet; and, taking this effect to be uniform, the shrinkage in 2,000 years would be only 0.12 of a foot, or exactly 0.01 part of the calculated elevation due to earthquakes. Now in the above calculation of the expansion due to earthquakes, we may have taken the disturbed area too large; but one uplift in four great disturbances does not seem to be an over estimation of the effects of elevation. The sinking of the sea bottom, however, goes on, and less frequently the land along the shore is carried down also; and possibly the elevation is relatively less than we have computed. As this calculated expansion is 100 times the shrinkage, we might reduce the size of the uplifted areas to 100 miles square, and still the expansion would exceed the contraction by 25 times. We could again reduce the areas to 50 miles square and make the uplift over 6 times the contraction. If, however, the uplifts be restricted to the areas covered by the land, the effect would be quadrupled. To make the expansion just equal to the contraction we should have to reduce the amount of the average vertical uplifts from 2 feet to 1 inch, or make the 2-foot uplifts 24 times less frequent, so that only one would occur in 96 great earthquakes.

This seems to be excessively small, and I think it practically certain that the expansion of the globe is from 10 to 100 times more rapid than the contraction, in the evaluation of which we have used Daniell's maximum estimate.

When we contemplate the mountains and plateaus, we see that an expansion of our globe is indicated by its general aspects. For it is in this manner that the mighty mountains have been upraised, and the vast plateaus uplifted, without greatly depressing large areas of the sea bottom. As the earth is almost totally devoid of shrinkage due to secular cooling, the maximum estimate being 1.44 inches in 2,000 years, this most probably indicates a secular expansion of our planet. In any given age the expansion is not equally effective all over the terrestrial spheroid, but the present distance of many mountains and plateaus from the sea shows that

it goes on steadily, and in times gives rise to large effects over considerable belts. It seems therefore practically impossible to avoid the conclusion that our earth is not contracting at all, but on the contrary is actually undergoing a slow secular expansion. In any given geological age the areas uplifted may be confined to particular regions, chiefly along the sea coasts, but in the long run it will include a large part of the earth's surface. In the course of ages more and more land is raised above the sea, which at the same time is contracting its extent and decreasing its total volume by the secular desiccation arising from the gradual absorption of the waters into the rocks of the earth.

§ 12. *Researches Founded on the Hypothesis of the Gravitational Instability of the Terrestrial Spheroid Rest on a False Premise.*— Quite recently several of the most learned mathematicians in England have treated of the uplift of the continents and their secular movements, on the hypothesis that these effects are due to gravitational instability in the progressive shrinkage of our planet. It is scarcely necessary to point out that in order to reach correct conclusions we must start from correct premises, as well as follow an unbroken chain of reasoning. One may readily concede that the learned discussions which have appeared from several eminent investigators are perfect specimens of the logical art, and adorned with flawless mathematics. But if the premises are not well founded in nature, the superstructure built thereupon necessarily falls to the ground. It does not seem to have occurred to these learned investigators to examine critically the underlying premises, for no doubt they assumed the historical doctrine of secular cooling and contraction of the globe as unassailable.

From our study of this question, however, it seems certain that the earth's cooling is infinitely slow, and that no sensible contraction or other movements depend on this cause. The observed movements are always near the sea, which shows that they depend in some way upon the oceans. As the land is frequently upheaved along the sea coast, and all the mountains and plateaus have been thus uplifted, it is impossible for such movements to depend upon the mere settlement of a gravitationally unstable planet. Hence in the present en-

: of the earth we must reject the whole doctrine of
ınkage as false and misleading.

earth was once of larger volume and smaller density
›resent, there may have been a time when it was settling gravitational instability, *but this was long before the become encrusted.* Since the consolidation began the been excessively slow, and no convective circulation has :e within; consequently the planet has not since experienced ' se e gravitational instal , except that due to earthquakes trom the penetration of water vapor, which gives rise to mountain formation and kindred phenomena now witnessed at the surface of the earth. The theory of gravitational instability as applied to the earth therefore is not valid, because it applies to a far earlier stage in our history, before the crust had begun to form. The premise underlying this learned reasoning seems therefore false, and we can only look upon such an ingenious speculation as an interesting example of brilliant abstract reasoning, in no way applicable to the present or recent history of our planet. By no possibility could such theories enable us to explain the distribution of earthquakes, or their prevalence near deep seas, where trenches are being dug out in the sea bottom and mountains uplifted along the borders of these abysses.

What is said here in regard to these several investigations applies also to Professor Love's learned discussion of the gravitational instability of the earth, involving the various orders of spherical harmonics. His beautiful mathematical theory is a monument of ingenuity, correct on the hypothesis, but the latter is lacking in physical basis, and consequently the investigation is chiefly valuable as a piece of abstract reasoning of high order, interesting in dynamics, but not applicable to the development of our actual earth.

§ 13. *Views of the Late Professor James D. Dana on Mountain Formation.*—Among the many eminent geologists who have treated of mountain formation, the late Professor James D. Dana stands preëminent for having come nearest to the correct theory; and although the false hypothesis of the contraction of the earth underlies his views and vitiates them, yet they are sufficiently remarkable

to deserve the attention of the careful reader who seeks to follow the historical development of human thought. It is only by a survey of this kind that one gets an adequate perspective of the theories developed in the different ages. Dana's views are given in his "Manual of Geology," 1863, and the most interesting passages are the following:

(*A*). On page 29, he points out that the continents are all walled in by mountains erected about their borders, and adds:

(*a*) "The continents thus exemplify the law laid down, and not merely as to high borders around a depressed interior—a principle stated by many geographers—but also as to the highest border being on the side of the greatest ocean (first announced in *American Jour. Sci.* (2) XVII, vols. III, IV, 1847, and XXII, 335, 1856). The continents then are all built on one model, and in their structure and origin have a relation to the oceans that is of fundamental importance."

He also observes that the borders of continents are from 500 to 1,000 miles wide, and infers that "a continent can not be less than a thousand miles (twice five hundred) in width," otherwise it would not have the characteristic basin form with mountain barriers about a low interior.

(*b*) On page 731 he discusses the evolution of the earth's great outline and reliefs, and of the successive phases in its progress, summarizing his conclusions as follows:

I. "The continents have mountains along their borders, while the interior is relatively low; and these border mountain chains often consist of two or three ranges elevated at different epochs."

II. "The highest mountain-border faces the largest ocean, and conversely."

III. "The continents have their volcanoes mainly on their borders, the interior being almost wholly without them, although they were largely covered with salt water from the Azoic age to the Tertiary. Also metamorphic rocks later than the Azoic age are most prevalent near the borders."

IV. "Nearly all of the volcanoes of a continent are on the border which faces the largest ocean."

V. "The strata of the continental borders are for the most part plicated on a grand scale, while those of the interior are relatively but little disturbed."

VI. "The successive changes of level on coasts, even from the Azoic age to the Tertiary, have been in general parallel to the borders of mountain chains; as those of the eastern United States, parallel to the Appalachians, and those of the Pacific side, as far as now appears, parallel to the Rocky Mountains."

VIII. "The continents and oceans had their general outline or form defined in earliest time. This has been proved with regard to North America from the position and distribution of the first beds of the Lower Silurian—those of the Potsdam epoch. The facts indicate that the continent of North America had its surface near tide-level, part above and part below it (p. 196), and this will probably be proved to be the conditions in Primordial time of the other continents also. And, if the outlines of the continents were marked out, it follows that the outlines of the oceans were no less so."

The three other conclusions announced by Dana are of less interest, and need not be quoted here.

(*B*). The following deductions (p. 732) regarding the positions of the reliefs are of high interest:

"1. The situation of the great mountain chains, mainly near the borders of the continents, does not indicate whether the elevating pressure acted within the continental or oceanic part of the earth's crust. But the occurrence between the principal range and the seacoast of the larger part of the volcanoes (and, therefore, of the profound and widely-opened fractures) of these borders, of the most extensive metamorphic areas, and of the closest and most numerous plications of the strata, as so well shown in North America, are sufficient evidence that the force acted most strongly from the oceanic direction."

"2. The relation between the extent of the oceans and the height and volcanic action, etc., of their borders proves that the amount of force in action had some relation to the size and depth of the oceanic basin. The Pacific exhibits its greatness in the lofty mountains and volcanoes which begirt it."

"3. In such a movement, elevation in one part supposes necessarily subsidence in another; and, while the continental was the part of the crust which was elevated, the oceanic was the subsiding part."

In connection with the theory that the mountains are formed by the expulsion of lava from beneath the sea, through the operation of world-shaking earthquakes, these early views of Dana are of great interest. But in other respects he was led astray by the doctrine of the secular refrigeration of the globe; for he says that "no other cause presents itself that can comprehend in its action the whole globe and all time." He thus speaks as if the entire globe were shrinking, whereas local changes only are occurring, and these always near the sea. Dana's view that "the pressure of the subsiding oceanic portion has acted against the resisting mass of the continents; and thus the border between them has become elevated, plicated, metamorphosed and embossed with volcanoes," is alike

misleading and unjustifiable. For to produce such an effect the settling of the ocean basin would have to be many miles, and we have shown that no such shrinkage has taken place since the crust was formed; on the contrary there is reason to think that the earth is expanding at a rate of from 10 to 100 times that of the contraction due to secular cooling. Moreover we have no more right to assume that the continent is squeezed by the settling of the ocean, than that the ocean is squeezed by the settling of the continent.

We have, however, recalled these views in order to do justice to the most original of the older American geologists, and also to let the student see where he departs from the true line of thought. Many years ago Rev. O. Fisher showed that shrinkage was wholly inadequate to account for the height of the mountains observed upon the earth, which are hundreds of times higher than the contraction theory will explain. In the paper on the cause of earthquakes it is shown that the contraction theory is also emphatically contradicted by the present distribution of mountains. In the present paper and that "On the Temperature, Secular Cooling and Contraction of the Earth, and on the Theory of Earthquakes held by the Ancients," it appears that at present the earth is not contracting at all; so that we are compelled to abandon the older theories entirely.

As heretofore developed geology has presented the strange anomaly of offering no theories adequate to account for the uplift of mountains and plateaus or the deposits of fossil beds thousands of feet above the sea. This is the more remarkable, since in the days of Humboldt, Lyell, and Darwin, the bodily elevation of the land was an accepted item of belief. But subsequently Lord Kelvin, Sir George Darwin, and other eminent British physicists, showed, from the investigation of tidal and other phenomena, that the earth as a whole behaves as a solid; and under the influence of this line of thought geologists gave up the doctrine of the bodily elevation of the land, and restricted themselves to the collapse of portions of the crust under gravity. The theory of collapse, however, utterly fails to explain mountains and plateaus and islands, as well as shells and other organic remains at great height above the sea level. But it was felt that the argument of the physicists against the bodily

yielding of the earth was unanswerable, and so it is for the globe as a whole; yet this does not disprove the existence of a layer just beneath the crust which in earthquakes behaves as fluid*

In the present researches a theory is developed by which these two views may be reconciled, and it is, I think, clearly proved that in earthquakes there is movement of molten rock beneath the earth's crust. It is this movement of molten rock beneath the crust which produces most of the dislocations, crumpling, folding, and fault phenomena studied in geology. If such a theory is justifiable, it shows us how cautious we must be in drawing final conclusions, and how incomplete all the sciences still are to-day.

§ 14. *Criticisms of the Theory here Adopted.*—Not many criticisms of weight have reached the writer since the publication of the papers on the "Cause of Earthquakes" and the "Temperature of the Earth," but he may here notice two to which some attention may be given.

1. *A geologist thinks that the absence of volcanoes about the South Atlantic is difficult to explain.* This supposed difficulty is much less real than it seems; for some submarine volcanoes have been known in that region, and a good many submarine earthquakes. The sea is shallow near the borders, but a long tableland is rising in the center, and we have no means of knowing how many disturbances occur in this region, which is comparatively seldom visited by ships. Probably the lava finds an avenue of escape under this submarine plateau, and some sea waves occur from time to time, but the region is too far from land to produce great inundations of the shore. As the land is not yet lifted into a sharp ridge, the mountains do not yet appear above the water, and such eruptions as occur beneath the

* Since this was written Professor Wiechert of Göttingen has presented the International Seismological Association in session at the Hague, Sept. 1–26, 1907, a report of the chief results of his researches on the internal constitution of the earth. The existence of long vibrations in the tremors propagated by earthquakes, with periods of eighteen seconds or more, reveals, he thinks, the presence of a layer of liquid or plastic material at a depth of about thirty kilometers from the surface. (See report of meeting by Professor Harry Fielding Reid in Science, Jan. 10, 1908.) Note added Jan. 22, 1908.

sea pass unnoticed. It is not remarkable, therefore, that we find so few volcanoes in this region, and the absence of known volcanoes in no way contradicts the theory. Volcanoes usually break out after mountain ridges are folded sharply upward; this stage may come later in the South Atlantic, where the sea is neither very deep nor the gradient very steep near the shores. Consequently in such a region we should not expect at present many volcanoes or great visible earthquake effects.

2. *Some geologists have believed also that the steam escaping from volcanoes comes from the central magma of the globe.* But if this were true, as we have pointed out in the paper on the "Temperature of the Earth" (p. 288), the volcanic outbreaks ought to occur in the interior of the continents as well as near the oceans. For the vapor ascending from the central magma of the globe could not always be deflected around the immense extent of the continents, and appear only at their edges, and in the depths of the sea. The geographical distribution of volcanoes therefore effectively contradicts any such hypothesis.

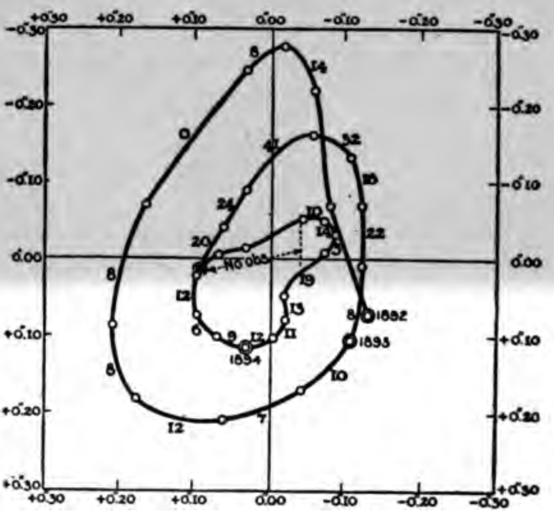
§ 15. *The Criticism based on the Supposed Coincidence of Great Earthquakes with the Sudden Shifting of the Earth's Axis in its Revolution about the Mean Axis of Figure.*—A reviewer of the paper on the "Cause of Earthquakes," in *Nature,* August 1, 1907, after admitting the adequacy of the cause assigned to explain most phenomena finally adds:

> "But his (See's) explanation fails to account for the remarkable connection between the irregular shifting of the earth's axis and the occurrence of the greatest earthquakes. That these irregular movements of the axis are greatest when large earthquakes are most frequent is a certain, but as yet unexplained, fact; it seems to necessitate displacement of matter in the earth on a far larger scale than is indicated by the differential measurements which alone are open to us. Professor See's explanation, though it provides for lateral and vertical displacement of matter, necessitates the elevations and depressions being so closely contiguous as practically to neutralize each other's effects, and, therefore, fails as an explanation of the ultimate cause of earthquakes, while it in no way affects the current acceptance of fracture as their immediate cause."

This criticism is not well founded, and after what has been said above and in the two preceding papers, probably does not require

any elaborate notice; yet we may briefly point out the weakness of the position taken, which seems to be the same as that announced by Professor Milne in his Bakerian Lecture to the Royal Society, 1906, where he says:

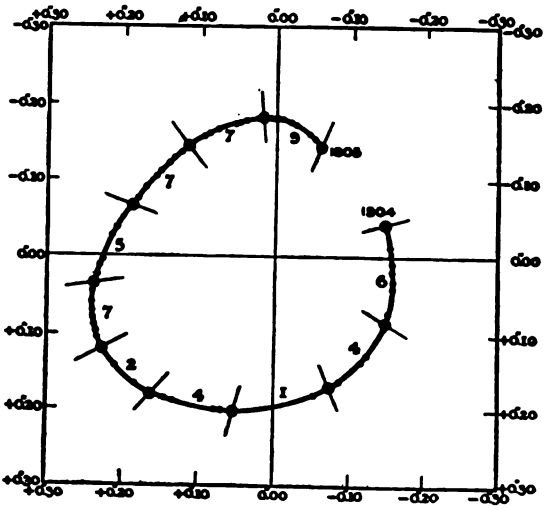
"If we take a chart showing the varying position of our earth's north pole in relation to its mean position, we see that the secular movement of the pole is by no means uniform. Although it may at times follow a path about its mean position which is approximately circular, at other times there are comparatively sharp changes in direction of motion which may even become retrograde. If now on a chart of this description we mark the time positions of very large earthquakes, we find that they cluster around the sharper bends of the pole path." (See the accompanying figures with explanations taken from Professor Milne's paper.)



"FIG. 1. After Th. Albrecht. The path of the North Pole from 1892 to 1894 inclusive. Each year is divided into tenths or periods of 36.5 days. Numerals indicate the number of large earthquakes which occurred in each of these divisions, commencing with the third tenth of 1892."

"In a period of nearly 13 years (1892 to 1904) I find records for at least 750 world-shaking earthquakes, which may be referred to three periods continuous with each other, and each two tenths of a year or 73 days' duration. The first period occurs when the pole movement followed an approximately straight line or curve of large radius, the second equal period when it was undergoing deflection or following a path of short radius, and the third when the movement was similar to that of the first period. The numbers of earthquakes in each of these periods taken in the order named were

211, 307 and 232, that is to say, during the period when the change in direction of motion has been comparatively rapid, the relief of seismic strain has not only been marked, but it has been localized along the junctions of land blocks and land plains where we should expect to find that the effect of general disturbances was at a maximum. It can hardly be assumed that the



"FIG. 2. This is similar to Fig. 1, but refers to the year 1903, during which period the pole displacement was more uniform than that indicated in Fig. 1."

frequency under consideration is directly connected with change in direction of pole movement; but it seems not unlikely that both effects may arise from the same redistribution of surface material by ocean currents and meteorological causes generally."

This reasoning of Milne asserts that the greatest earthquakes occur when the path of the pole bends most rapidly. In reply to this claim we may remark in the first place that it is very doubtful whether a general law of this kind can be fairly deduced from existing observations, because the path of the pole depends on such minute quantities that the curvatures platted may not be real. In the second place, if the assumed law were admitted, the meaning of it would still be open to interpretation, and several of these could no doubt be made without involving a contradiction of known laws.

For the total displacement of the pole from the mean position is nearly always less than 30 feet, and generally less than 15 feet;

these movements correspond to quantities represented in arc by 0″.30 and 0″.15, which are on the very limits of our most accurate astronomical measurements. The apparently sharp turns in the pole path, therefore, may not be real, but merely a delusion arising from some unknown cause. If, however, these sharp turns are real, this fact cannot be certainly established till the polar motion has been repeated many times, and the data now available do not seem sufficient for this purpose.

Moreover, even if the sharp turns are real and it could be proved that the great earthquakes gathered about them, in regard to which there is still much doubt, our interpretation of the results would be open to much uncertainty. For it could not be inferred that large masses of matter are in motion within the earth, and that the displacement of these masses causes a sudden change in the movement of the pole. We have seen that the matter of the earth's interior is kept rigid by pressure, and that no movement deep down in the globe ever takes place. This is shown by the fact that a shock originating deep down would be felt with moderately uniform intensity over a large area, which is disproved by observations showing that all great earthquakes are quite superficial. If no shocks originate at great depth, the only other possible movement would be just beneath the crust; and it is quite impossible that currents could move for great distances just beneath the surface without disturbing the whole intervening region of the globe.

Much as has been done on this difficult subject by the greatest mathematicians, it is not yet known what causes operate to displace the pole from the mean axis of figure, and maintain the displacement in spite of friction and viscosity; but recurring seasonal effects, together with the imperfect rigidity of the earth, have been generally accepted as the chief causes. Is it not, therefore, probable that whatever displaces the pole and thus maintains its revolution about the mean pole, according to the Eulerian Theory as modified by viscosity and imperfect rigidity, may suffer variations through combinations of storms, and other atmospheric and tidal agencies? And that these combinations of varying stresses operate to bring on earthquakes where instability of the crust already exists, from the accumulation of subterranean steam pressure?

These combinations of circumstances are not the dynamical *cause* of the earthquakes, but only the *occasion* for outbreaks when instability is already developed. It might thus be that earthquakes would break out when the polar motion is changing most rapidly, *but the earthquakes do not cause the change; rather they are occasioned by that which makes the change.* Milne's view above quoted does not seem to differ much from this, for he says that " both effects may arise from the same redistribution of surface material by ocean currents and meteorological causes generally," though he overlooks the leakage of the oceans as the cumulative dynamical cause of instability.

On these grounds probably very few will agree with Professor Milne, if he is the reviewer quoted in *Nature,* that the present explanation fails. The facts which he assumes are not proved, and even if they were, the interpretation should be exactly the reverse of that which he has given in *Nature.* Consequently we may dismiss this whole criticism as not well taken. Nothing is more certain than that movements of large masses within the earth adequate to displace the polar motion do not take place. A supposed effect of this kind is contradicted by all that we know of the rigidity and solidity of the earth under pressure of its own mass, which would prevent deep movements, and by the well-established fact that all earthquakes are shallow and the shock limited to one locality. Movements in the sea and in the atmosphere, however, might conspire to displace the pole and vary its rate of movement about the mean position, and the stresses thereby exerted upon the globe might occasion seismic outbreaks where the steam pressure had already approached the limits of stability. If the facts assumed by Professor Milne, are confirmed by time and experience, it is in this way that they must be explained; the outbreak of earthquakes being *occasioned,* but not *caused,* by the surface movements of water and air which displace the pole from its mean position and vary its rate of movement in different parts of the path, and thereby also the stresses exerted upon the different parts of the already unstable revolving globe.

§ 16. *On an Explanation of the Squeezing up of the Continents by the Settlement of the Ocean Basins given in Some Works on*

Geology.—In the work on "Geology" by Chamberlin and Salisbury, Vol. II., p. 129, we find the following curious figure and explanation of the elevation of the continents:

FIG. 3. Illustration of general deformative movement, from Chamberlin and Salisbury's "Geology," Vol. II., p. 129.

"FIG. 32 *C*. Diagram illustrating the supposed elements of a general deformative movement. *SS* represents the outline of the sphere at the ocean level before deformation. The dotted line represents the corresponding surface of the lithosphere, the ocean basin occupying the center and the continents the flanks. *S'S'* represents the outline of the sphere at the ocean level after deformation, the heavy line representing the outer surface of the deformed lithosphere, and the space between *SS* and *S'S'* representing (much exaggerated relatively) the vertical shrinkage which is the great feature of the movement but is only made apparent through its deforming effects. That part of the outer shell which is beneath the ocean is supposed to descend without much compression, while the necessary folding is concentrated on the borders of the continent. The central portion beneath the ocean is represented as descending directly toward the center. The portions on each side preserve their length by thrusting laterally and hence descend along paths represented by the arrow-headed lines, of which those at the border of the ocean, *a*, *a'*, are the most oblique and represent the greatest thrust. On the borders of the continent the crust is folded to the extent of this lateral thrust. This of course only holds true when the thrust is limited to a single oceanic basin. The lateral thrust is chiefly felt in the outer shell or rigid zone, *RZ*, which embraces the heavy line and the dotted zone below. Beneath this lies the shear zone, *SZ*, whose foliated structure is represented as not unlike that of the 'drag' belt of a fault plane. The igneous sheets, batholiths, etc., which are supposed to especially affect this zone are not represented. The great

sector beneath the ocean is represented as having crowded slightly upon the sectors beneath the continents on either hand, this crowding being represented by the short arrows *b*, *b'*. By comparing *bb'* with *aa'* the reason for the shear zone will be made apparent. On the right-hand side the outer part of the sub-oceanic sector is represented as crowding upon the continental sector an exceptional amount, as represented by the deflection of the line *b'b''*. This gives rise to the plateau at the right. The proportions of most of the significant parts are necessarily exaggerated relatively."

Let us now analyse this explanation a little more closely. These authors remark that "that part of the outer shell which is beneath the ocean is supposed to descend without much compression, while the necessary folding is concentrated on the borders of the continent." Is not this a purely gratuitous assumption, simply begging the question, and wholly unjustifiable? Why should the oceans descend without compression, while the continents are squeezed up at their edges? Obviously one has as much right to assume that the oceans are compressed by the sinking of the continents, as that the continents are compressed by the sinking of the oceans. Again, they say that "the portions on each side preserve their length by thrusting laterally and hence descend along paths represented by the arrow-headed lines, etc." But does not the assumption that "the portions preserve their length" imply that the ocean segment has not shrunk at all in respect to surface area, while the continent has been squeezed up at the edge to let it go down?

What right have we to assume a similar shrinkage in the radius of these sectors, and admit a shrinkage in one surface area (the continental) but deny it in another (the oceanic), which is much the larger of the two?

Could one imagine a more improbable effect of secular cooling?

Moreover the above figure corresponds to a shrinkage of about one tenth of the radius, or 400 miles. In view of the fact which has been shown in the paper on the "Temperature of the Earth" that our globe is not shrinking at all, it is unnecessary to make further comment on this unauthorized procedure.

But we may remark that in this "Geology," Vol. II., p. 131, we find a direct contradiction of the above explanation. It runs as follows:

"The continents now rise about 3 miles above the average ocean bottom, and much more than that in certain portions. Since the volume of the ocean has probably not greatly changed during known geological time and since the continents appear to have risen above surface, about as now, in the earliest known geological ages, it is assumed that similar differences of relief have prevailed at the various known deformative periods. We have seen that the gravitative pressure at 3 miles' depth is nearly or quite as great as the shearing-resistance at that depth. If a shearing-zone at depths of 3 to 5 miles had already been developed during the primary deformation, this would facilitate a reversed movement along the same shear-planes. It is therefore conceived that the continental platforms, by pressing upon their bases to the extent of 16,000 to 30,000 pounds to the square inch, would, though opposed by perhaps 5,000 pounds per square inch pressure from the oceans, gradually creep laterally under their own gravity, in a slow glacier-like way. This supposed lateral creep should be attended by crevassing, fissuring, and normal faulting; in other words, *by the prevalent tensional phenomena which the continents present.* It should be much more marked in the plateau regions than elsewhere, because of their superior elevation, and it is there that normal faulting is most pronounced."

Thus in one place we are assured that the continents have been squeezed up, in another that they are creeping down in a slow glacier-like way. If they are creeping down how were the mountains elevated? And why should these uplifts appear at the borders of the continents? Perhaps it will be answered that these two movements are going on together. But does not the first principle of the new theory tell us that neither of these supposed movements has any reality, and that the mountains and plateaus are elevated by the expulsion of lava from beneath the sea, the shells of which are thus carried to the greatest height in the gradual uplift of the land?

§ 17. *On the Folding and Distortion of the Strata seen at the Earth's Surface.*—In many works on geology the crumpling and folding of the strata are attributed to "a gentle warping of the soil." No doubt where mere settlement of the ground is in progress, owing to undermining, there is some warping of the soil; but this implies that the strata have already been uplifted and undermined, so as to become unstable. Such uplifting is the work of earthquakes, during past geological ages, though the settlement and warping may be due to the gradual undermining effects of water or other agency which produces instability. All movements of this kind are of small importance compared to the greater and more violent

derangements due to earthquakes. Many of the dislocations of the strata now seen on land originated when they were beneath the sea, and it would be a mistake to attribute any considerable part of these movements to seasonal or meteorological influences. It may be that the shape of the two sides of a valley undergoes an infinitesimal deformation from these causes, yet no important effects depend on such small deformations. They are all very superficial in character, whereas the causes which have folded the rocks of the earth's crust have been much more deep seated, and originate principally in earthquakes. When we see folded strata laid bare by erosion therefore we may assign the greater part of such effects to the "gentle warping of the soil" experienced in the dreadful shakings and derangements due to earthquakes of the world-shaking class. In observed plications of the strata earthquakes have supplied the principal part of the disturbing force. The important uplifts have all arisen in this way, and the instability thus resulting has produced the smaller displacements noted where the earth is settling.

The ground is more or less flexible near the surface, and sensible sagging may be produced by loading, but such effects are shallow and small in amount, and it would be a mistake to attribute to this cause important deformations of the strata. Is not such phraseology as the "gentle warping of the soil" therefore very unfortunate and misleading, and should it not be entirely given up?

§ 18. *Radium and other Atomic Sources of Energy.*—In the paper on the "Temperature of the Earth" we adhered to the gravitational theory as the only one which could be subjected to strict calculation. It is of course possible that there may exist in our planet unknown sources of atomic or subatomic energy such as are shown in radium and the related elements, which exhibit similar radio-active properties. At present, however, the amount of these elements known to exist in the earth is excessively small, and although this might account for the earth's internal heat; yet as gravitation is known to be a real cause and has been found sufficient to explain the observed phenomena, it is natural that a known source of energy which can be subjected to strict calculation should be preferred to one which is so wholly unknown.

Thus while we confined our estimates and calculations to gravitational energy, we do not deny the possibility that other sources of energy of an atomic or radioactive character may exist. If such sources really exist, the effect would be to prolong the period of the earth's history since consolidation.

At the present it is impossible to estimate these effects with any approach to accuracy, and we have therefore preferred to await the results of future research.

Our knowledge of radium and the rôle it plays in cosmical development is still much too limited to permit even a rough estimate of the effects of such subatomic energy. But it seems certain that radium has no sensible connection with volcanic eruptions, since in the rocks underlying the great extent of the continents it remains quiescent, and gives rise to no kind of outbreaks, though it may raise slightly the temperature of certain mineral springs. Remarkable as radium is, and wonderful as are its chemical actions, we are still unable to say that it plays any sensible part in cosmical processes outside of chemical transformations which lie in the domain of Mineralogy. The energy liberated in these transformations might, however, greatly prolong the past history of the earth, and the total duration might thus be extended from 10 to 100 million years.

III. On the Disturbances of the Earth's Magnetism by Earthquake and Volcanic Phenomena.

§ 19. *Observations Show That Earthquakes and Volcanic Outbreaks Often Disturb Terrestrial Magnetism.*—It has long been noticed that volcanic outbreaks and also earthquakes are not infrequently accompanied by temporary disturbances of the earth's magnetic field. The cause of this is not yet understood and any conjecture at this time may be premature, nevertheless we are inclined to call attention to certain features of these phenomena which should be borne in mind.

1. As the earth's crust is thin, and the interior at an immense temperature, it seems highly probable, if not certain, that the magnetism of the globe depends upon the crust and the atmosphere, together with the sun's variable magnetic field in which our planet

revolves. That the incandescent nucleus could effect the magnetism of the earth seems highly improbable.

2. The annual and diurnal variations of the magnetic needle are most easily explained by the seasonal and diurnal effects of the sun, exerted indirectly through the paramagnetic medium of the atmosphere, the electric forces of which are modified by the sun's varying radiation of charged particles.

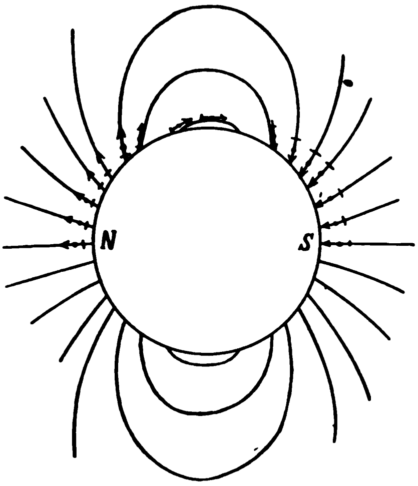


FIG. 4. Showing the lines of force about a spherical magnet, or a magnetized spherical shell, such as the crust of the Earth.

3. The aurora is one of these effects and has been treated by Arrhenius with characteristic penetration.

§ 20. *Gauss' Analysis of the Earth's Magnetism and the Conclusions Which May be Drawn From it.*—If we denote by $d\mu$ the quantity of magnetism present in an element of space, and by ρ its distance from any point in space, whose rectangular coördinates referred to any system may be x, y, z; then we have for the potential function of the earth's magnetism

$$V = \int \frac{d\mu}{\rho}, \tag{1}$$

where the integration is to be extended over the entire volume of the earth. The forces resolved parallel to the coördinate axes are

$$-\frac{\partial V}{\partial x}=\xi,\quad -\frac{\partial V}{\partial y}=\eta,\quad -\frac{\partial V}{\partial z}=\zeta, \tag{2}$$

ting force is given by the diagonal of the parallelo-

$$f=\sqrt{\xi^2+\eta^2+\zeta^2}. \tag{3}$$

rection and intensity of the force is found by observation desired elements may be calculated.

; to polar coördinat... ...s denotes by r the distance of t from the ... r ... earth, and by u the angle which r m ... the north ... axis, and by λ the angle with the meridian made a plane passing through the point and this polar axis. Symbols with subscripts zero refer to points in the earth.

Hence the expression for the distnce ρ from any point in space is

$$\rho^2=r^2-2rr_0[\cos u\cos u_0+\sin u\sin u_0\cos(\lambda-\lambda_0)]+r_0^2. \tag{4}$$

Accordingly the expression for the potential becomes

$$V=\int\frac{d\mu}{\sqrt{r^2-2rr_0[\cos u\cos u_0+\sin u\sin u_0\cos(\lambda-\lambda_0)]+r^2}}. \tag{5}$$

Considering the earth to be a sphere of radius a Gauss puts

$$-V=\frac{a^2}{r}P^0+\frac{a^3}{r^2}P'+\frac{a^4}{r^3}P''+\frac{a^5}{r^4}P'''+\cdots; \tag{6}$$

the coefficients, P^0, P', P'', etc., are functions of λ and u only.

If we develop the denominator under the integral sign in (5) in a series, the first two members of the series become

$$\frac{1}{r}+\frac{r_0}{r^2}[\cos u\cos u_0+\sin u\sin u_0\cos(\lambda-\lambda_0)]+\frac{r_0^2}{r^3}+\cdots, \tag{7}$$

whence

$$a^2P^0=-\int d\mu,\quad a^3P'=-\{\alpha\cos u+\beta\cos\lambda+\gamma\sin u\sin\lambda\},$$

where

$$\alpha=\int r_0d\mu\cos u_0,\quad \beta=\int r_0d\mu\sin u_0\cos\lambda_0,\quad \gamma=\int r_0d\mu\sin u\sin\lambda. \tag{8}$$

As Gauss took the northern and southern magnetism to be equal and of opposite sign, it follows that

$$\int d\mu=0,$$

and $P^0 = 0$. Hence we may put for points at the earth's surface, where $r = a$, and $P^0 = 0$.

$$-V = a(P' + P'' + P''' + \cdots), \quad (9)$$

where P', P'', P''', depend only on u and λ.

The magnetic potential for the earth calculated in this way represents observations with the desired accuracy. Since Gauss showed that any distribution of magnetism within the earth, as respects the effects in outer space, may be completely represented by an appropriate surface distribution, it follows that the existing distribution of the earth's magnetism is most probably confined to the crust of the globe. In fact this is the only part of our planet sufficiently cooled to maintain magnetic properties once established in its elements. The field of force thus arising about the earth might, however, be slightly modified by electric and other effects depending on the sun and moon, and the diurnal movement of the illuminated hemispheres of our globe. These effects as determined by observation are much too large to be ascribed to direct actions of the sun and moon, and are believed to be indirect effects depending largely on charges operating in the upper regions of our atmosphere.

This upper atmosphere is always exposed to the radiation of the heavenly bodies, and no doubt accumulates a potential powerful enough to influence the field near the earth's surface. Discharge of this potential is witnessed in the aurora borealis, which is accompanied by conspicuous disturbances of the earth's magnetism. Gauss showed that the location of the constant part of the earth's magnetism must necessarily be in the body of the globe, and not in the atmosphere or outer space.

In his "Algemeine Theorie des Erdmagnetismus," 1838, Gauss treated of a sphere magnetised in any manner. If X, Y, Z, be the components of the earth's resultant magnetic force at any point on the surface, in the directions of geographical north, west and the zenith of observer, the horizontal intensity H, declination δ, and inclination ι, are fully defined by the equations:

$$H = \sqrt{X^2 + Y^2}, \quad \tan\delta = \frac{Y}{X}, \quad \tan\iota = \frac{Z}{\sqrt{X^2 + Y^2}}. \quad (10)$$

If V be the magnetic potential of the earth, l the latitude, and λ the longitude of any point on its surface, and if a be the radius of the earth assumed to be spherical, we shall have

$$X = -\frac{1}{a}\frac{\partial V}{\partial l}, \quad Y = -\frac{1}{a \cos l}\frac{\partial V}{\partial \lambda}, \quad Z = -\frac{\partial V}{\partial r}, \quad (11)$$

where r is the distance of any point from the center of the earth.

If $S_1 + S_2 + S_3 + \cdots S_i$ be a convergent series of spherical surface harmonics defining for every point of its surface the potential of all the magnetized molten or electric currents within the earth, the potential at all external points will be given by the series

$$V = S_1\left(\frac{a}{r}\right)^2 + S_2\left(\frac{a}{r}\right)^3 + \cdots + S_i\left(\frac{a}{r}\right)^{i+1}. \quad (12)$$

The functions S_1, S_2, S_3, . . . are functions of known form, containing 3, 5, $\cdots$ $2i + 1$ constants; and if we neglect terms beyond the ith order, there will remain in the expression for V $i^2 + 2i$ arbitrary constants. These constants may be determined by observation, and then the magnetic action at all points on the surface or outside the earth becomes known irrespective of the internal distribution of the magnetic causes which are inaccessible to observation.

§21. *The Mutual Potential Energy and Mutual Action of Two Magnetic Systems.*—If any portion of the earth's crust or an atmospheric current above it should be suddenly magnetized by an instantaneous charge of electricity or otherwise, during the violent commotion of an earthquake or volcanic outburst, we should have at least a temporary magnet suddenly formed in the field of the earth's magnetism, and the result would be the disturbance of the magnetic needle. Whether the magnetism of the earth be distributed according to Poisson's theory, with a certain volume distribution of density v and a surface distribution of density σ; or according to Gauss' theory, with a distribution wholly on the surface, this result is equally true.

To determine the mutual action of two magnets on each other requires the evaluation of a sextuple integral, every point in one field of space acting upon the corresponding points of the other. If W be the potential energy of the whole magnetic system, R and R'

the resultant forces at any point of space due to the acting and acted-upon systems respectively, θ the angle between their directions, and dv the element of volume occupied by any element of magnetism, we have (Encyclopedia Britannica, article "Magnetism," p. 230):

$$W = + \frac{1}{4\pi} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} RR' \cos \theta dv. \qquad (13)$$

Now unless R or R' is zero, so that the elements of the triple integral vanish, or one of the magnets exerts only an infinitesimal force upon the other, this mutual potential energy is always finite. Accordingly, whenever a new magnet of sensible power is suddenly developed in the field of the earth's magnetism, the magnetic needle necessarily is disturbed, as in earthquakes and volcanic outbursts. The fact that such disturbances are so repeatedly observed, leaves no doubt of the development of temporary magnets in the earth's field of force; and the intensity of the disturbance necessarily is greatest near the place where the second magnet is developed. Hence the disturbance of the needle by such outbreaks indicates the generation of temporary magnets in the earth's crust, and especially in the atmosphere. The dissipation of the charge restores quiescence to the earth's magnetic field, and the needle ceases to tremble.

§ 22. *Terrestrial Magnetism Modified by Irregularities in the Earth's Crust.*—In the *National Geographic Magazine* for September, 1907, Dr. L. A. Bauer has a review of the work done by the *Galilee* in the survey of the North Pacific ocean authorized by the Carnegie Institution. After describing the work already done he adds:

> "An all-sailing vessel, however, does not permit the magnetic survey to be undertaken with the completeness and success demanded, since with such a vessel it is more or less dangerous to investigate the magnetic irregularities almost invariably shown to exist near land masses. The mapping of these irregularities is of the greatest importance to the mariner, as in many cases they are sufficient, if not allowed for, to land a vessel on the rocks."

The land masses accessible to the navigator are either islands or shores, and thus irregularities of surface like the mountains which we see on land; and the change in the magnetism near mountains is also well known. It follows therefore that irregularities of sur-

fect the magnetic needle in the neighboring region. ıs effect would not be likely to arise if the magne- a on the whole earth, rather than on the crust, and ms to indicate that the seat of the earth's magnetism is ""ally shallow. Not only may we attribute the permanent mag- the crust, but we may also affirm that the upheavals of which have produced mountains have given rise to varia- ı the local field.

Just how this arises may not be firmed with entire certainty; but the fact that disturbances have b en noted during earthquakes would seem to indicate bodily movement of magnetic matter, or ordinary matter temporarily rendered magnetic.

The outburst at Mt. Pelée, May 8, 1902, which instantly disturbed the magnetic needle over a wide area, was probably due to the ejection of a great mass of burning vapor high into the air, which thus gave rise to such electric energy that the earth's magnetic field was suddenly disturbed.

The eruption at Krakatoa produced a very similar effect, the sudden development of an atmospheric charge vastly exceeding that due to the greatest hurricane. (Report of the Krakatoa Committee, Royal Society, 1887.) A hurricane develops gradually and the effect is scattered over a wide area; a volcanic outburst is sudden and so concentrated that a considerable disturbance of the earth's magnetic field may easily result. It is somewhat analogous to the aurora borealis, but the location and cause is different and the effect may be less rapid. In the aurora there is a discharge between the upper and lower regions of the atmosphere, and this redistribution of the magnetic tension in the earth's atmospheric system causes a fluctuation of the magnetic needle, or a so-called magnetic storm.

Now in the case of a violent volcanic outbreak there is a similar disturbance, owing to the sudden injection of a highly electrified charge into the lower parts of the atmosphere, and the exchange with the upper region continues for some time. Also when great earthquakes occur there is violent shaking of a considerable region of the earth's crust, and consequently some temporary, and perhaps permanent, derangement of the elements of magnetism, owing

to the agitation and to the movement of streams beneath the crust. These seem to be the most probable causes of the changes in the earth's magnetic field, often noticed to disturb the needle at the time of earthquakes and volcanic eruptions; but our knowledge of the subject is still in its infancy and we must be cautious in drawing conclusions. Some of the disturbances of course are purely mechanical.

The comparatively slow propagation (868 miles per hour) of the magnetic disturbance at the time of the Krakatoa outbreak, August 27, 1883, might be ascribed to the undulatory commotion in the upper air, since sound so propagated would have about this velocity. It would seem to depend more upon the indirect effects of a disturbance of the air than upon the forces exerted by a direct magnetic charge. Both causes are no doubt at work in certain disturbances, and time must decide just how the effects are propagated.

Conclusion.

At the close of the two former papers on the physics of the earth, the chief results at which we arrived are briefly summarized. In the same way we may here add a recapitulation of the results which are more fully established in this third paper.

1. It has long been customary to refer mountain making to catastrophes in remote geological ages, and to suppose that the formation of mountains is not going on upon the earth at the present time. Such supposed spasmodic activity is contrary to the whole order of nature and to the doctrine of evolution by which we labor to interpret animate and inanimate phenomena. On the other hand the discovery of mountains in the depths of the sea has excited the surprise without satisfying the wonder of the naturalist, so that the whole subject has become involved in darkness.

2. The doctrine of continuity, as respects both time and space, permits us to view earthquakes, mountain formation, and kindred phenomena, merely as a part of an unbroken whole which has come about by the steady action of natural laws operating not only along the borders of the continents, but also in the depths of the ocean. A theory which unites and harmonizes these phenomena,

and thus explains the mountains on land, as well as those in the depths of the sea, by a common cause, operating not only throughout past geological ages, but also at the present time, will naturally have a strong claim to acceptance.

3. We have therefore labored to establish some undeniable cases of mountain formation now going on in the depths of the sea, and have shown by the theory of probability, based merely on contiguity of positions and similarity of volume between the deep trench off the Aleutian Islands and the ridge which runs parallel to it, with peaks here and there projecting above the water as islands, that the chances are at least a decillion decillions to one that the ridge and adjacent depression are physically connected and have had a common origin. As an island of the ridge is frequently uplifted by an earthquake, while the bottom of the trench sinks, as shown by the withdrawal of the water before the inrush of the accompanying seismic sea wave; and as this corresponds to an expulsion of lava from beneath the trench towards the land, or away from the body of the Pacific ocean, and the volume of the ridge corresponds to that of the trench, the probability that one developed from the other is converted into an absolute certainty.

4. The expulsion of lava from the ocean towards the land and the breaking out of numerous islands into volcanoes, emitting chiefly vapor of steam, shows that the subterranean movement can depend on nothing whatever but the secular leakage of the ocean bottom, which is most rapid where the sea is deepest, in accordance with the observed recurrence of earthquake phenomena.

5. Undeniable cases of mountain formation now going on in the depths of the sea may thus be located in various parts of the world. We have cited such cases in the Aleutian, Kurile, and Japanese islands; in the East Indies, between New Zealand and Samoa, and along the coasts of various continents. Many more may be found by the further study of the sea bottom and of the earthquakes now disturbing it.

6. It thus seems undeniable that earthquakes in the sea and along the sea coasts have the highest geological significance. In fact no other forces are at work crumpling the earth's crust, as seen in mountain ranges, islands, and plateaus; and the absence

of mountain forming movements in the interior of the continents shows that all these effects depend upon the sea, or upon surface water generally, and not at all upon the progress of the secular cooling of the globe.

7. Researches into the physics of the earth based on the hypothesis of gravitational instability may be interesting mathematically, but a study of the earth's surface shows that all the important crustal movements now going on result from the influence of the sea; and hence the conclusions deduced from the theory of gravitational instability are invalid, because, ingenious and correct as they are on the hypothesis, they rest on a false premise.

8. In the same way it is shown that no sensible shrinkage results from secular cooling; on the contrary the globe seems to be undergoing a gradual secular expansion, owing to the influence of the sea in uplifting mountains, plateaus and other masses of land, by the injection of lava saturated with steam, which forms underlying masses of pumice of various degrees of density. The expansion of the globe seems to be at least ten times more rapid than the contraction due to secular cooling; and the great distance to which the sea has withdrawn from some of the mountain ranges, and the great height to which the plateaus have been uplifted, exhibits the mighty effects of this cause in the course of geological ages.

9. The seat of terrestrial magnetism seems to be the earth's crust and the surrounding atmosphere; irregularities in the magnetic forces arise from the sun and moon, while similar disturbances accompany earthquakes and volcanic outbreaks, which suddenly agitate the air and change the electric condition of matter in the field of the earth's magnetism. The irregularities near islands and land masses noticed in ocean surveys indicate that the permanent magnetism is confined chiefly to the solid crust, and does not depend on the great incandescent nucleus of the globe. Magnetic storms and aurorae depend on atmospheric charges derived principally from the sun and moon.

10. It is thus proved not only that earthquakes, volcanoes, mountain formation, the formation of islands and plateaus, seismic sea waves, and the feeble attraction of mountains long noticed in

geodesy, are closely connected and mutually dependent upon a single physical cause, namely the secular leakage of the ocean bottoms; but also that the magnetism of the earth is intimately connected with the forces which modify the earth's crust, because the chief seat of the permanent magnetism is shallow. Thus seven great classes of natural phenomena are shown to be mutually connected and dependent on the forces which have crumpled the crust of our planet.

11. In the paper on the temperature of the earth it was shown from the mathematical theory of heat as applied to the secular cooling of the globe that when the gravitational potential of the mass alone is the source of energy considered, the most probable age of the consolidated earth is some ten million years. Variations of the data there used might possibly double this age, but it is doubtful if further extension of the time limit of the past history of our planet is possible without invoking the aid of subatomic energies as exemplified in radium and kindred radio-active substances. At present we know too little of radium and similar elements to be able to affirm with confidence that the heat resulting from the transformation of these substances does not prolong the life of our planet; yet as radium has no known connection with volcanoes, earthquakes, and mountain formation, but, from the absence of outbreaks in the interior of continents, seems to be everywhere in an essentially quiescent or dormant condition, it is natural to infer that it plays only a subordinate part in cosmical processes. It may, however, be of great importance in chemical transformations, which belong to the domain of Mineralogy, and relate to the crust, rather than to the body, of our globe. Without, therefore, wholly denying the cosmical importance of radium, we calmly await developments which will show its correct place in the order of nature. As the energy derived from radium would counteract the effects of secular cooling it may have greatly prolonged the history of the encrusted earth.

12. In the investigation of phenomena so complex as those connected with the physics of the earth, we must not expect the real underlying physical cause to be entirely clear in every case, because the present state of the globe presents to our contemplation natural

processes in every stage of development, and the aspect obviously will be different in different stages. If we can find the true laws exemplified in a few typical cases in which the meaning of the phenomena is free from doubt, we may legimately hold that in all cases the phenomena were more or less similar at one stage of their existence. Considering the vast age of the earth and the insignificant period of human history, and the much briefer time covered by intelligent observations, we seem indeed fortunate to be able to recognize the true processes in even a few typical cases of crustal transformation. For the life of the individual is as nothing in the history of our planet. Accordingly the simplest natural laws, which lie at the basis of the physics of the earth, we have discovered and confirmed beyond all doubt; and we may safely leave to the future the extension and verification of the theory of the secular leakage of the ocean bottoms, of which we have been able to lay only the general foundation.

But even a mere outline of the processes which lie at the basis of the physics of the earth is likely to clarify and simplify our views of the order of nature. The complete development of that beautiful science will be a work of the future, and for the present we must rest content with the recognition of true physical causes, without which order and harmony and proper relationship between different classes of phenomena could not be established, however great the number of observations. The chief danger in science to-day is that in the midst of such vast multitudes of special observations as are being accumulated, the few true causes, which give order and harmony to the whole body of phenomena, will be lost sight of. Without these underlying principles for guiding our thought, according to nature's laws, the mere accumulation of disconnected facts may become a burden to oppress, rather than a starry ray to illuminate, the human mind. Principles are therefore vastly more important than observations, though accurate observations always are required in their deduction; because where the underlying laws are confirmed they give the solid foundations for a real science, which enable us to understand the observations of all time.

Blue Ridge on Loutre,
Montgomery City, Missouri, October 24, 1907.

ADDENDUM.

§ 23. *On the Sinking of Deep Trenches in the Sea Bottom.*—Since the above paper was finished it has occurred to the writer to point out a little more clearly the circumstances which may lead to the sinking of the sea bottom, when lava is expelled from beneath it. In the accompanying figure, the process of mountain formation is supposed to be going on. The expulsions of lava naturally are accompanied by a sudden relief of crustal stress, and a mighty horizontal thrust in the direction of the movement, as the lava is pushed under the land.

This terrific lateral pressure is powerful enough to push the lava along under the crust, in spite of the great weight of the latter. By this enforced movement the ridge is elevated, as at *b*, and at the

same time the crustal block moved a good many feet in the direction of the land; this stretches the sagging crust, and pulls it apart along certain fault lines under the sea, as at *a;* so that when some of the support from beneath is withdrawn by the expulsion of part of the supporting lava, and the fault opened, by the horizontal movement, the crust naturally gives down. The shaking accompanying the horizontal thrust of the crust opens the fault under the sea, thus temporarily removing the friction of one crustal block against another and permitting the walls to slide without great resistance. And as the support is weakened by the simultaneous expulsion of part of the underlying lava, sinking necessarily follows.

From these considerations we see that sinking is most easily brought about where the ridge is sharply elevated so as to permit some lateral movement. It is true that the inclination of the crustal block throws a little more weight on the side under the sea and this would increase the resistance; yet when the fault is opened during the vibrations of an earthquake sinking the more easily takes place. This explanation enables us to understand why sinking of the sea

bottom, as shown by the accompanying seismic sea wave, so frequently occurs during great earthquakes.

The force of the argument that the ridge was uplifted by matter actually expelled from under the trench is easily seen from a familiar illustration often met with in a smooth field or on the plains. If we go along over the level ground, and all of a sudden come upon a mound with a sink hole near it of about the same volume, we immediately conclude that the mound builders or pond diggers have been at work. It is obvious that the mound is made of soil which came out of the hole. In the same way, if we came upon a ditch with a ridge to one side, of such volume that it would about fill up the former, we know with even greater certainty that ditch diggers have taken the soil out of the trench and piled it upon the bank.

Now the trenches in the sea bottom, with parallel ridges of nearly equal volume, have all the force of this familiar argument; but as they have not been dug from above, it follows that the matter is transferred beneath the crust, by subterranean bodily movement of the kind we have described; and hence the crust has been crumpled correspondingly, the ridge running parallel to the trench from which the matter was expelled.

§ 24. *On Darwin's Theory of Coral Islands.*—This investigation throws decided light upon Charles Darwin's famous theory of the sinking of the ocean bottom, as inferred from the study of the coral reefs. It shows that while sinking often takes place, elevation also is very common. The chief difference is that elevation kills the coral, and the islands gradually become covered with vegetation, while only those in which sinking predominates become surrounded by coral reefs. It is well known that there are many islands in the sea with coral rock above the water; a good illustration is afforded by the eastern end of Guam, where a huge block has been uplifted, as shown by the vertical walls. Islands which have been recently uplifted often are volcanic, so that coral appears especially about old islands, many of which are subsiding, owing to a change in the direction of movement beneath the crust. Forces which formerly produced elevation are now changed in direction and working so as to produce a slow subsidence. Charles Darwin's theory of coral reefs is therefore confirmed, but it does not explain all the phe-

nomena noticed about the islands in the sea. It happens also that some islands once built around by coral are again upraised by a recurrence of the elevating movement; yet this probably would not be the usual phenomenon, so that in general Darwin's observations on coral reefs accord with the theory, and are what one might naturally expect to find on an ocean-covered planet with leaky and oscillating crust.

§ 25. *On the Modification of Secular Cooling by Radium.*—In regard to the age of the earth, it ought to be remarked that if radium be taken into account, the heat resulting from its secular disintegration would prevent the crust from thickening, except very slowly; and consequently with so thin a crust as that of our actual globe the period of time since the consolidation, as calculated in the paper on the "Temperature of the Earth," is too small. Accordingly although we found the period to be of the order of ten million years, yet if radium be introduced the duration of time might be lengthened to one hundred million years, or even to a greater period. And if this energy due to radium be admitted for the earth, it could not well be denied for the sun, so that the period of the sun's activity would be lengthened correspondingly. Hence the more moderate of the immense periods of time demanded by geological phenomena may be conceded. Time must decide to what extent these demands are justifiable. At present we may await future developments with entire confidence that the causes now known are sufficient to explain all terrestrial phenomena.

§ 26. *Favorable Reception of the Present Theory by Physicists and Geologists.*—The lively interest awakened by the two preceding papers among physicists and geologists and other men of science, as shown by letters which have reached the writer, indicates a much more favorable reception of the present theory than might have been anticipated. Indeed its general acceptance seems fully assured, and many questions are thus raised of great importance in natural philosophy. All who have considered the question attentively seem to agree that it is very improbable that the ocean bottom is watertight. One of the most eminent of living physicists expresses the opinion that this cannot be true, unless the nature of the rock is greatly modified by pressure. Such modification under pressure he

thinks cannot take place in the first twenty miles of the earth's crust, because the pressure is not great enough to prevent secular leakage under the constant pressure of the oceans, which in many places is sufficiently powerful to throw a column of water five miles high.

No doubt this view will be generally adopted by physicists and geologists. One may indeed see that it is true by remembering that at a depth of twenty miles the pressure is only about 8,600 atmospheres, or a little over eight times what it is in the deepest oceans. Such pressure might indeed tighten the crystalline elements of granite, but it could not obliterate the crystals; and hence capillary forces would be intensified rather than diminished by this tightening up of such a coarse-grained structure.

We cannot experiment on rock subjected to such pressure as exists at a depth of twenty miles, but we can observe lava expelled from volcanoes, some of which was once compressed at this depth; and we can examine the granite at the base of vertical walls where faults have moved under earthquake forces for many thousands of feet. In neither case does the structure of the rock indicate that great modification would occur at so small a depth as twenty miles.

But the most conclusive answer which nature gives to this inquiry is furnished by the vast vertical walls of granite so often lifted thousands of feet by fault movements in such places as the Andes of Peru, Chile and Patagonia, where the leakage of the ocean has found relief by the expulsion of lava under the land along the margins of the sea. The meaning of the mountain formation along such a sea coast admits of no possible doubt. Accordingly we are enabled to interpret the movements beneath the crust, and to infer the nature of the underlying rock, even where it is wholly inaccessible to observation.

Blue Ridge on Loutre,
Montgomery City, Missouri,
Jan. 14, 1908.

Errata.

(*a*) In the paper on the Cause of Earthquakes:

On page 311 the formula for n should read $n = \frac{4400}{66} = 66\frac{2}{3}$.

The account of the changes produced by the Valparaiso earthquake, p. 328, appear to be open to some doubt. Exact data are not yet at hand. This detail of course does not affect the argument in the paper.

(*b*) In the paper on the "Temperature of the Earth":

(1) On page 196 the formula should read $\frac{Q}{W} = \frac{k - \epsilon}{k - 1}$.

(2) Near bottom of page 196, and middle of page 197, Auwendungen should read Anwendungen.

(3) On page 216, $\frac{d\theta}{dx}$ is taken to be $\frac{1}{51}$; and the exponential factor is neglected, because it appears in the second power, and for a depth of twenty miles is equivalent to $e^{-\frac{10^{20}}{(16)^2 10^{20}}} = e^{-\frac{1}{256}}$ and thus nearly unity for $t = 100{,}000{,}000$ years; for $t = 10{,}000{,}000$ years, the result is $e^{-\frac{1}{2.56}} = \frac{1}{1.48}$, which would make t still smaller, in the ratio of nearly 2/3 (0.676). There is therefore a slight defect in the solution for values of t so small as 10,000,000 years; but as it reduces the time to a still smaller interval, we need not further consider it. The values of t given in the paper on the "Temperature of the Earth" are therefore slightly too large for rigorous solutions of the equations.

SOME OF THE RESULTS OF ASTRONOMICAL PHOTOGRAPHY PERTAINING SPECIALLY TO THE WORK WITH A PORTRAIT LENS.

(Plates I–VI.)

By E. E. BARNARD.

(Read April 20, 1907.)

In the present paper I wish to offer a few specimens of astronomical photographs which have been made with portrait lenses. These pictures, which are from my own work, are fair samples of what can be done with this class of lens. They have been selected to show the variety and extent of the work, which covers the Milky Way, the nebulæ, the larger star clusters, meteors, comets, the earth-lit and the totally eclipsed moon, etc. Most of the pictures were made with the 10-inch Brashear lens of the Bruce telescope of the Yerkes Observatory.

The Advantages of Photography in Astronomy.

Before the application of photography to the study of the heavens, one saw the sky but poorly indeed, and in the light of the revelations of the photographic plate today, one is almost tempted to say that he did not see the heavens at all, so vastly has photography enlightened us as to the actual appearance of the sky and its citizens.

There are two causes that have helped to produce this wonderful power that photography has given us. First, above all, the great sensitiveness of the photographic plate over that of the human eye. Second, the fact that our plates show us a vastly larger space of the heavens than the visual telescope does—in some cases a thousand times greater than is shown by our most powerful telescopes of today. A wide field of view is of the utmost importance in the study of the tails of comets, of the larger nebulæ and of the

cloud forms and structure of the Milky Way, for these in general are very large. The field of view of a visual telescope, which is at most but a mere speck of the sky, is entirely too small to take in the whole of such an object. In the case of the Milky Way, the structural details are on such a grand scale that their true forms could not even be guessed at with the ordinary telescope. The importance, therefore, of the large field that the photographic plate gives us is very evident.

But there is one thing which we must take into account. The time element enters strongly into the photographic part. One may look into a telescope and he will see at once, if the conditions are favorable, the faint star or faint nebula he has in the field of view—it is but a moment that the eye takes to fix the image before it. Perhaps some very faint and difficult object may require a little longer, but it is only because a special moment of steadiness is waited for. The photographic telescope with its highly sensitive plate will not catch the object in that same time. It may require an hour or more before it "sees" it. But with the eye there is no cumulative effect; on the contrary, indeed, it soon becomes tired, so that in a sense, the longer you look the less you see, merely from the fatigue of the eye. With the plate there is no fatigue. The longer it looks the more it sees, so, though it may take it an hour to see what the eye readily perceives in a moment, it does not stop at that point but goes on seeing more yet, the longer it looks. In this way it soon registers things that the eye cannot perceive at all with equal optical means, and in many cases it reveals objects—especially among the nebulæ—that the eye may never see in the actual sky. And, what is of immense advantage, it permanently records what it sees, so that the exact appearance of a nebula may be preserved for future reference perhaps hundreds of years hence, while the view obtained by the eye is as evanescent as the fleeting glimpse of the object itself. Even though the observer should make a careful drawing it is too often worthless, and misleading, for reference with other drawings, made later on; for the astronomer is seldom or never an artist.

If one examines drawings of the same celestial object by different observers, he is often struck with the want of agreement in

these pictures. There are a few of the more prominent nebulæ such as the celebrated ones of Orion and Andromeda, which have been drawn by many observers. There is a strange want of resemblance among these pictures, and what is worse still there is often but little resemblance to the object itself. There was always the possible excuse that the object had actually changed its appearance in the sky. Photography, however, in the past twenty years has shown that such appreciable changes have not really occurred, though they must occur in the course of time.

The best illustration of this want of harmony in different delineations of the same astronomical subject is shown in the large number of drawings of the solar corona made by numerous observers at the total eclipse of the sun in 1878 which were collected and published by the United States government. No two of the forty odd drawings closely resembled each other and few of them looked at all like the indifferent photographs obtained at the time. Indeed these drawings and other similar ones led an eminent astronomer four years later to declare that the corona was not a real phenomenon belonging to the sun, but that it was partly a diffraction effect and partly in the eye of the observer, so that each observer, as it were, saw a different phenomenon—an idea that no one would think of holding today when photography has long since clearly demonstrated the solar origin of the corona.

The real cause of these various discrepancies lay mainly in the want of artistic skill in the observer, who saw the things all right but was unable to draw them correctly, especially was this so in the case of an eclipse of the sun, where the excitement of the moment was enough to unnerve most observers.

Perhaps the greatest sufferer from this want of pictorial skill was the occasional comet. These bodies are really subject to remarkable and rapid changes and hence a misrepresentation was all the more unfortunate. In the case of the nebulæ one could simply throw out the poor representations as being due to lack of skill. In the case of the comet no one can tell whether the want of agreement in the various drawings was not due to actual changes in the comet itself. Happily today, the lack of artistic skill in the individual plays almost no part in astronomical work. The photo-

graphic plate, not only with an accuracy far beyond that of the most skillful artist, but with an eye almost infinitely more sensitive, sees the faintest details of a comet or a nebula and records them with a faithfulness unheard of before.

Today the sensitive plate is not only taking the place of the astronomical draughtsman, but it is also running the most skillful measurer a close race. The facility and ease with which great numbers of star places can be measured on the photographic plate, commend it to the most exacting astronomer.

Photography has materially altered our ideas of the nebular theory. From the views of the nebulæ with telescopes not sufficiently powerful to properly deal with them, and hence with views that were more or less erroneous, a theory was elaborated that appealed to the popular mind with a wonderful fascination. There is much that must be changed in this theory to meet the rigid requirements of modern science and to satisfy the demands of what has been revealed in the forms of the nebulæ by the photographic plate.

It is in dealing with the nebulæ that astronomical photography has attained one of its most remarkable triumphs. These bodies in reality shine with a light that has comparatively little effect on the human eye but to which the photographic plate is singularly sensitive. To our eyes the nebulæ are seen "through a glass darkly," as it were, while to the eye of the sensitive plate they are more or less brilliant objects.

Our old ideas of the dimensions of these vast bodies have also been greatly changed. In the days of purely visual astronomy, the great nebula of Orion, covering as it does some half a degree of the sky, was looked upon as inconceivably great in actual extent in space —yet photography has not only increased its extent very greatly, but it has revealed other nebulæ, unknown to us before, that are hundreds of times vaster than this great nebula of Orion. The Pleiades are in the midst of a mighty system of nebulosity that covers at least one hundred square degrees of the sky, and whose actual extent in space almost defies calculation.

Four or five degrees north of the star Antares, in the Scorpion. is a faint star just fairly visible to the naked eye. This is known

as Rho Ophiuchi. If one examines the space about this star with a telescope he sees nothing remarkable except that there are fewer small stars in this region—yet photography shows us that the sky here is covered by an enormous and magnificent nebula which apparently lies in a hole in the sky. From this great vacant region—vacant in the sense of there being few or no stars in it—narrow dark lanes run eastward for many degrees. But the singular thing is that the nebula seems in some way to be responsible for the absence of stars at this point. Whether this is due to the obscuration of the light of the small stars that ought to be here, by the nebula, which would in that case prove it to be nearer to us than the stars, or whether the presence of the nebula has in some way destroyed or dispersed the stars cannot be told.

Perhaps the most extraordinary revelations of photography in astronomy have been in the case of comets. These wonderful objects with their vast trains sweeping through space are singularly subject to disturbances by other celestial bodies. The photographic plate has shown us that the comets utterly transform themselves in a few hours' time, for, though of vast dimensions, they are in reality but flimsy affairs with little or no solidity. In these changes, so faithfully recorded by photography, they sometimes, through the distortions of their trains, reveal the presence of some kind of resisting medium or of some unknown bodies through whose attraction, or by collision with which their tails are twisted, broken or deformed in the most extraordinary manner. This was the case with one of the comets of 1893 where photographs on successive nights show the tail disrupted and broken, undoubtedly by such an encounter. What this really means we have yet to learn. Possibly the comet passed through a dense swarm of meteoric bodies in its flight around the sun. Photographs of another comet showed the tail entirely separated from the head and drifting away in space. From these last pictures it was shown that the particles forming the tail were leaving the comet with a velocity of twenty-nine miles a second.

Importance of the Portrait Lens.

The strangest thing in connection with these statements is that the greater portion of these photographic revelations have been made

with instruments that are extremely crude in comparison with the elaborate and expensive telescopes with which our great observatories are equipped today. Indeed in many cases the lenses were not made for the purpose to which they have been put. It was only incidentally that their services came to be of benefit to astronomy. I have often thought of the strange difference in the present use of these lenses and the one for which they were originally made. Though it would be hardly fair to attribute their origin to the purpose of human vanity, it was certainly vanity that had much to do with it, for these large lenses were made purely for the taking of portraits. In the days of the wet plate process the slowness of the sensitive agent used in the plates made it necessary to employ very large lenses so as to collect a greater quantity of light, and thus to shorten the time of the sittings. Their use has therefore not fallen to a lower level but has risen to a much higher one—from the picturing of human vanity in the human face to the picturing of the sublime features of the face of the heavens. Their great light grasping power is no longer needed for the enlightenment of human vanity—not that that evil has in any way become extinct—but from the fact that with the extremely rapid dry plates of today the work can be done with very much smaller and less expensive lenses.

Description of Plates.

Nebulæ and Nebulosities.

For an example of nebular photography with a portrait lens perhaps one of the best specimens is that of Plate I (exposure 4 hours), which shows the "North American Nebula." Though this plate does not represent all that is visible on the original negative, it yet shows how beautiful the nebula is, and how appropriate was Dr. Max Wolf's naming of it. The nebula is not a faint object with a telescope—indeed it was discovered over a hundred years ago by Sir William Herschel. It is not, however, suited for visual observations. With a small telescope one sees only a diffusion of feeble light which has no definite form or limits. It is, nevertheless, excellently and specially adapted for photographic representation because of the peculiarity of its light, which is very rich in photo-

graphic qualities. A long exposure, however, is required to show the fainter outlying masses of nebulosity which are clearly shown in the present picture. This photograph was made with the 10-inch Bruce portrait lens of the Yerkes Observatory in the splendid atmosphere of Mount Wilson, California, where the writer had taken it in 1905, through the courtesy of Professor Hale, for the photographing of the Milky Way.

This picture exemplifies in a striking manner a peculiarity which is often found in connection with these large nebulosities and to which I have frequently called attention. That is, the apparently free mixture of stars and nebulosity without any evidence of condensation of the nebulosity about the stars. I don't think this is necessarily a case of accidental projection of the stars and nebulosity, for there are numerous similar cases in the sky. In the present case one can trace out a similarity of configuration of the outlines of the nebula and the massing of the stars, which would strengthen the idea that they are at the same distance from us. This fine object is in the Milky Way a short distance east of Alpha Cygni, which star is shown at the western edge of the plate.

A good example of the fainter and more difficult nebulosities is shown in Plate IV, the nebulous region of Gamma Cygni (exposure 6 hours 30 minutes). These nebulosities are not visible with the telescope because of their exceeding faintness. Their full extent is not shown in the photograph, for they extend considerably beyond the limits of the plate. It will be seen that Gamma Cygni, the star in the middle of the picture, is in a region of diffused nebulous matter which extends over a large area and is gathered in masses of greater brightness at different points, but is in general formless and diffused.

The lower picture of Plate IV is a still finer example of the photographic nebulosities—*i. e.*, nebulosities that are too faint to be seen with the telescope and for the knowledge of which we are dependent on the photographic plate. This is the magnificent region of the great nebula of Rho Ophiuchi (exposure 4 hours 30 minutes). Unfortunately the reproduction is a failure, for much of the nebulosity and the great vacancies connected with it, that are so wonderfully shown in the original, are all but lost in this half-tone.

I think there is no other region in the entire sky so remarkable as this of which Rho Ophiuchi appears to be the center. The great nebula itself, which seems to cover almost this entire region with its extensions, and its association with the extraordinary star vacancy here are very puzzling, and lead one to believe that the apparent paucity of small stars at this point is due in some way to the presence of the nebula. The great dark lane or rift running to the east, extends as far as the region of Theta Ophiuchi and seems to be a part of the system of vacancies that occur to the east and south of Theta.

The great nebula is full of remarkable details. There are a number of principal condensations, that of Rho Ophiuchi being perhaps the most striking. The nebula extends to, and involves the bright naked-eye star Sigma Scorpii in a strong condensation full of details. In several wave-like masses it involves and reaches bёyond Antares, one of the brightest stars in the sky. It seems to faintly cover a great part of the sky here, extending so far north, perhaps, as to connect with the remarkable nebula about Nu Scorpii. There are traces of it extending as far south as Tau Scorpii.

Perhaps as remarkable as ȧnything in connection with this nebula is the fact that it is so faint that the eye, armed with the most powerful telescope, cannot see it. Its light seems to be almost entirely photographic, and though too faint to be seen in the telescope it is doubtless very bright to the photographic plate.

At the lower part of this plate, a half inch to the left of the small cluster (M 4), is apparently an ordinary star. This is the bright red star Antares which is the brightest in this region of the sky, but which, from its red color, appears quite small and insignificant on the photograph. A half inch above the cluster is the star Sigma Scorpii which is much less than Antares. Sigma Scorpii is the center of a bright condensation of the nebulosity which in the original is seen to connect with the larger nebulosity (in the middle of the plate) about the star Rho Ophiuchi. The dark lanes running from the nebula east, though strong and conspicuous in the original, are nearly lost in the reproduction.

The first picture in Plate II is a photograph of the region of the double cluster of Perseus (exposure 5 hours 55 minutes), which

gives a good idea of the gradual massing of the stars from a region of uniform distribution into two clusters whose stars are brighter than the average of that part of the sky.

Meteors.

The unpredicted appearance of the occasional meteor, the suddenness with which it appears and the rapidity of its flight across the sky, make it impossible to locate its path with exactness by eye observations alone; though observers skilled in this class of work can secure a close approximation to the path. If two such observers are separated by several miles, a fair idea may be obtained of the distance of the meteor and of its actual path through our atmosphere. In general, however, there is always much uncertainty attached to such results. What one really sees is a more or less bright point of light darting suddenly across the sky—the duration of whose flight seldom exceeds one second of time and the image of which vanishes from the brain almost as soon as it is formed. It may well be imagined how difficult is the exact location of the path of this fleeting point among the stars. If the meteor could have left a line of light on the sky along the full extent of its course for a few minutes, then one could locate its position fairly with respect to the stars, and yet this would still have considerable uncertainty attached to it from the fact that at best only an estimate (and no measures) could be made with the naked eye of the position.

In photographing the sky with wide angled lenses it is not an uncommon thing for a meteor to take its flight across the region which is being photographed. In this case when it is bright enough, the meteor actually does leave a permanent path among the stars; for the moving point of light affects the sensitive plate, continuously, marking out thus a "trail" among the star images, which is permanent and whose position can be measured with very great accuracy.

If a second camera, some distance from the first one, is also photographing the same part of the sky the meteor trail will be recorded by both cameras and its displacement on the two plates as photographed from these two points on the earth, can be determined accurately and the distance and path of the meteor will become

known. Such an instance occurred at the Yerkes Observatory where the same meteor was photographed with two cameras (by Mr. Frank Sullivan and the writer) separated by 400 feet only. The parallax or displacement of the trail among the stars was clearly shown. Measures of these two plates show that the meteor was about 90 miles above the earth's surface.

In Plates II and III are given specimens of meteor photographs selected from a great number of such plates. The lower photograph, of Plate II (region of M 11, exposure 2 hours 40 minutes), shows the trails of two meteors which were nearly in a straight line, so that, at first thought, one would suppose it was the trail of one meteor which had been interrupted near the middle of its flight. Both meteors were moving toward the south, it is assumed (for they were not seen by the observer), and were undoubtedly Lyrids —having a radiant in the constellation of Lyra.

Plate III (α 17 hours 20 minutes, δ south 15°; exposure 1 hour 34 minutes) shows in the first case the full flight of a meteor which evidently exploded near the end of its path, as indicated by that portion of the train which is of greater brightness. The lower photograph shows a great meteor trail and Brooks comet, IV, 1893 (exposure 2 hours 5 minutes). The bright trail was caused by a very large meteor which was seen by the observer. It was moving toward the southeast and exploded just off the edge of the plate. By one who is regularly photographing the sky with these rapid lenses, meteors are thus frequently caught in their flight.

Comets.

Plate V shows two views of Giacobini's comet (c 1905). The first of these (December 29, exposure 1 hour 38 minutes) is the most interesting because of the peculiar form of the tail of the comet. The edges of the tail are convex and sharply defined, and they taper to a narrow neck where they join the head, which is quite large. The tail was doubtless a hollow cone. There is a narrow hazy strip running from the lower or south edge of the tail near the middle of the plate. In the original this can be traced across the edge of the tail onto the tail itself. On the next night, December

30, all this definiteness of form had disappeared and the tail was very wide and diffused.

The lower plate (exposure 1 hour) is very interesting, but the main features of the tail are lost in the reproduction. Both photographs have suffered greatly in making the half-tones.

The Lunar Surface under Various Kinds of Light.

Plate VI shows two photographs of the moon. The size of the lunar image on photographs with a portrait lens (a half inch in diameter with the 10-inch telescope) is too small to be of any importance in the study of its crater and mountain-scarred surface. Such photographs, ordinarily, are, therefore, not worth the making. But there are conditions under which the moon may be photographed to advantage with these lenses—nor for a study of the craters and mountains, however. The first of these pictures (enlarged) shows the new moon with the slender sunlit crescent embracing the dark or night part, where no direct sunlight reaches the surface, or in other words it is the "old moon in the new moon's arms," which sometimes forms such a beautiful picture in the western sky at the vanishing of twilight when the moon is but a few days old. With the exception of the bright crescent, what we see is the lunar night, but it is a full "moon" night, for the illumination is entirely by sunlight reflected from the surface of the earth onto the night side of the moon. At that time if one were placed on this night part he would have seen the earth shining in the night sky like a great round moon (nearly full) some thirteen times bigger than the moon ever appears to us. The distinctness with which the lunar surface is shown in the photograph (with only 20 seconds' exposure) gives an idea of how brilliant the full earth must be when shining in the lunar night. This picture was made for comparison with the full moon and with the totally eclipsed moon, for the surface is then shown under three different kinds of illumination, *i. e.*, direct sunlight (full moon) reflected sunlight (earth lit moon) and refracted sunlight (totally eclipsed moon) to see if any difference could be detected in the appearance of the surface as affected by these various illuminations. Portrait lenses are specially suited for this purpose.

The second picture of this plate is a photograph of the totally

eclipsed moon (exposure 9 minutes) in which the only illumination is due to the sunlight refracted through the earth's atmosphere and bent into the shadow of the earth onto the moon. One of the reasons for making this picture was a hope that if any small body should be attending the moon in its journey around the earth (a small satellite for instance) it might be outside the shadow at the time, and being thus illuminated by the sun, would show on the photograph. The moon itself is ordinarily so bright that it would drown out the light of any faint body that might attend it.

Both the photographs of Plate VI are essentially ruined in the reproduction.

List of Lantern Slides.

This paper, when read, was illustrated by a number of lantern slides of the various photographs. A list of these is given below for completeness. I have arranged the slides in the order of subjects.

I. *The Earth-lit and the Totally Eclipsed Moon.*

Slide 1.—The new moon showing the lunar night, illuminated by the "full earth."

Slide 2.—This is the totally eclipsed moon illuminated only by refracted sunlight coming through the dense atmosphere near the earth's surface.

II. *The Milky Way, Star Clusters and Nebulæ.*

Slide 4.—The great star clouds of Sagittarius, east of the Scorpion.

Slide 5.—The double cluster of Perseus.

Slide 6.—The nebulous region of Gamma Cygni.

Slide 7.—The "North American Nebula" in Cygnus.

Slide 8.—The nebulous region of Rho Ophiuchi.

Slide 9.—The nebulosities of the Pleiades. This shows well the remarkable thread-like strips of nebulosity, especially the one from Electra and the one near and parallel to it. The extent of the nebulosities is greater than usually shown in photographs of the cluster. The original negative shows the exterior nebulosities surrounding the cluster. Exposure 3 hours 40 minutes.

III. *Meteors.*

Slide 10.—This shows two large meteors which followed nearly the same path across the plate.

Slide 11.—This shows the full flight of a large meteor on 1898, June 7.

Slide 12.—These two pictures are of the same meteor, but with two cameras 400 feet apart. The small scale picture was made by Mr. Frank Sullivan with 3.4-inch portrait lens attached to the 40-inch telescope during Professor Frost's spectroscopic observations. The other was made with the 6-inch lens of the Bruce photographic doublet. An inspection of the trail with respect to stars near which the meteor passed shows a decided parallax. The distance of the meteor above the earth's surface, from these two pictures, was about 90 miles.

IV. *Comets.*

Slide 13.—Swift's comet on 1892, April 7, showing a large mass and separate system of tails which were going out from the comet.

Slide 14.—Giacobini's comet, 1905, December 29. The picture shows the remarkable appearance of the tail, which on this date was quite unlike the tail of any other comet.

Slide 15.—Borrelly's comet on 1903, July 24. The second photograph on this slide was made by Mr. R. J. Wallace. The interval between the two pictures is 3 hours. The tail which was separated from the comet, had receded noticeably in three hours. Measures of the plates showed that the particles forming the tail were moving away from the comet at the rate of 29 miles a second. (See *Astrophysical Journal,* October, 1903.)

V. *Vacant Regions and Holes in the Heavens.*

Slide 16.—This is a remarkable region of vacancies in a great nebulous background in the constellation of Taurus. (See *Astrophysical Journal* for 1907, April.)

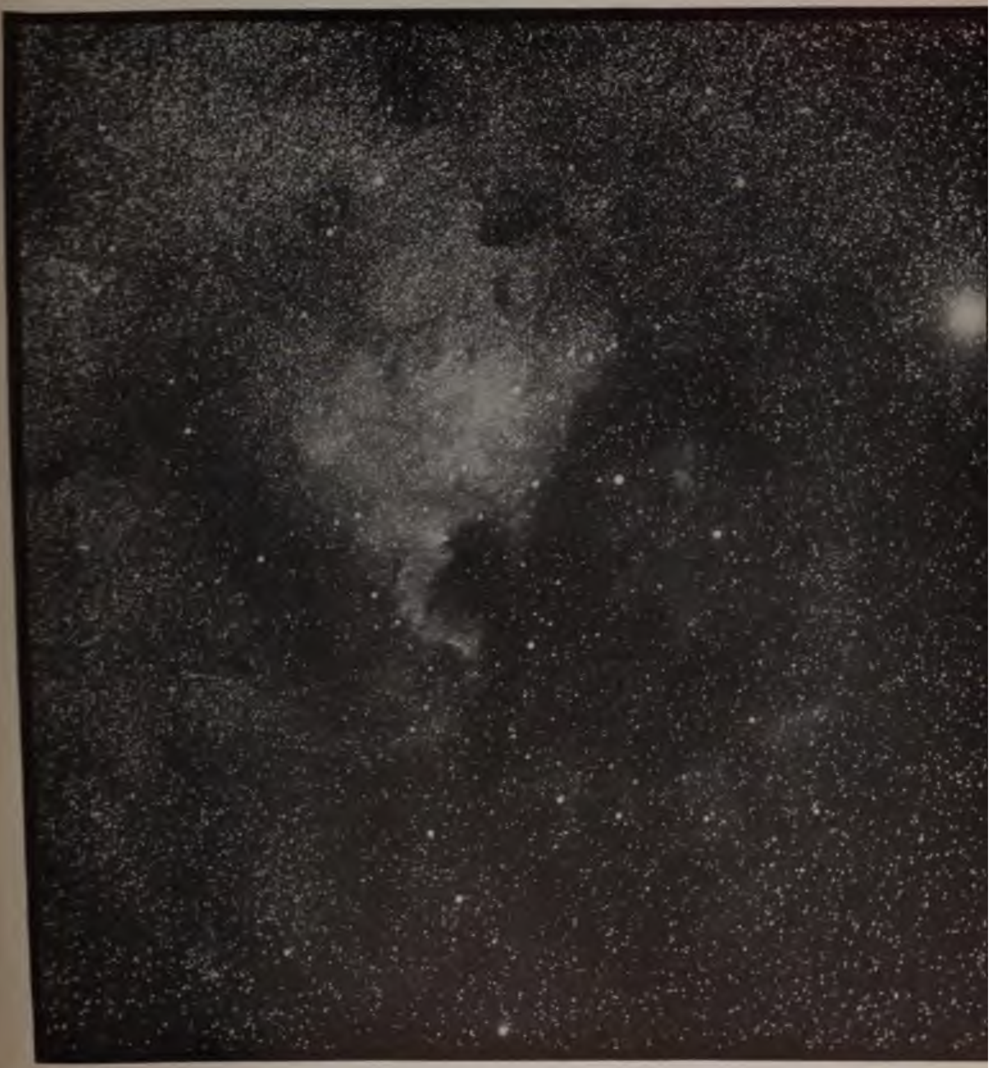
Slide 18.—Vacant lanes running from the nebulous region of Rho Ophiuchi towards the east.

Slide 19.—Great vacant regions about the star Theta Ophiuchi, (See *Popular Astronomy,* No. 140.)

YERKES OBSERVATORY, 1907.

PLATE I

N



North American Nebula
1905 September 4

Photographed with the Brue telescope
Yerkes Observatory

E. E. BARNARD

PLATE II

N

Double Cluster of Perseus
1904 September 15

N

Two Meteor Trails, and Star Cloud in Scutum
1904 April 20

Photographed with the Brue telescope
Yerkes Observatory

E. E. BARNARD

PLATE III

N

Meteor Trail
1899 June 7

N

Brooks' Comet and Meteor
1893 November 13

Photographed at the Yerkes and Lick Observatories

E. E. BARNARD

PLATE IV

N

Nebulous Region of Gamma Cygni
1905 August 28

N

Nebulous Region of Rho Ophiuchi
1905 April 5

Photographed with the Brue telescope
Yerkes Observatory

E. E. BARNARD

PLATE V

N

Giacobinis Comet
1905 December 29

N

Giacobinis Comet
1906 January 5

Photographed with the Brue telescope
Yerkes Observatory

E. E. BARNARD

PLATE VI

N

Earth-lit New Moon
1907 February 14

N

Total Eclipse of the Moon
1906 February 8

Photographed with the Brue telescope
Yerkes Observatory

E. E. BARNARD

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1886	DECHARENCEY, COMTE HYACINTH	25 Rue Barbet de Jouy, Paris, France.
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1904	CHITTENDEN, Prof. RUSSEL H., Ph.D.	83 Trumbull St., New Haven, Conn.
1906	CHOATE, Hon. JOSEPH HODGES, LL.D.	60 Wall St., New York, N. Y.
1902	CLARK, Prof. WILLIAM BULLOCK	Johns Hopkins University, Baltimore, Md.
1904	CLARKE FRANK WIGGLESWORTH, Sc.D.	U. S. Geological Survey, Washington, D. C.
1883	CLAYPOLE, Prof. E. W.	Pasadena, Cal.
1895	CLEEMANN, RICHARD A., M.D.	2135 Spruce St., Philadelphia.
1897	CLEVELAND, HON. GROVER	Westland, Princeton, N. J.
1902	COLLITZ, Prof. HERMANN, Ph.D.	Johns Hopkins University, Baltimore, Md.
1897	CONKLIN, Prof. EDWIN GRANT	University of Penn., Phila.
1898	CONVERSE, JOHN H.	500 N. Broad St., Phila.
1895	COOK, Hon. JOEL	849 N. Broad St., Phila.
1886	CORA, Prof. GUIDO	181 Via Nazionale, Rome, Italy.
1892	CRAMP, CHARLES H.	2113 DeLancey Place, Phila.
1877	CRANE, Prof. THOMAS FREDERICK	Cornell Univ., Ithaca, N. Y.
1886	CROOKES, SIR WILLIAM	7 Kensington Park Gardens, London, W., England.
1898	CROWELL, Prof. EDWARD P.	21 Amity St., Amherst, Mass.
1897	CULIN, STEWART	Brooklyn Institute of Arts and Sciences, Brooklyn, N. Y.

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1904	Da Costa, John Chalmers, M.D.	2045 Walnut St., Phila.
1897	Dall, Prof. William H.	U. S. National Museum, Washington, D. C.
1899	Dana, Charles E.	2013 DeLancey Place, Phila.
1896	Dana, Prof. Edward S.	Yale Univ., New Haven, Conn.
1902	Darboux, Jean-Gaston	36 Rue Gay-Lussac, Paris, France.
1898	Darwin, Sir George Howard, K.C.B.	Newnham Grange, Cambridge, England.
1907	Davenport, Charles Benedict, Ph.D.	Cold Spring Harbor, L. I., N. Y.
1876	Davenport, Sir Samuel	Beaumont, Adelaide, S. Australia.
1866	Davidson, Prof. George	2221 Washington St., San Francisco, Cal.
1899	Davis, Prof. William Morris	Cambridge, Mass.
1880	Dawkins, Prof. William Boyd	Woodhurst, Fallowfield, Manchester, England.
1899	Day, Frank Miles	Allen's Lane, Mount Airy, Philadelphia.
1905	Delage, Prof. Yves	Université de Paris, Station Zoologique de Roscoff, Paris, France.
1904	Delitzsch, Prof. Friedrich, Ph.D.	University of Berlin, Berlin, Germany.
1892	Dercum, Francis X., M.D.	1719 Walnut St., Phila.
1899	Dewar, Prof. James, LL.D.	1 Scroope Terrace, Cambridge, England.
1884	Dickson, Samuel	901 Clinton St., Philadelphia.
1892	Dixon, Samuel G., M.D.	Bryn Mawr, Pa.
1903	Dohrn, Dr. Anton	Marine Zoological Station, Naples, Italy.
1886	Dolley, Charles S., M.D.	3707 Woodland Ave., Phila.
1906	Donaldson, Henry Herbert, Ph.D.	Wistar Institute, 36th St. and Woodland Ave., Phila.
1886	Donner, Prof. Otto	Helsingfors, Finland.
1881	Doolittle, Prof. C. L.	Upper Darby, Delaware Co., Pa.
1903	Doolittle Eric	University of Pennsylvania, Philadelphia.
1899	Dougherty, Thomas Harvey	School House Lane, Germantown, Philadelphia.
1877	Douglas, James, LL.D.	Spuytenduyvil, New York, N. Y.
1880	Draper, Daniel, Ph.D.	Meteorological Observatory, Central Park, New York, N. Y.

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1906	Duane, Russell	2028 DeLancey Place, Phila.
1880	Du Bois, Patterson	401 S. 40th St., Philadelphia.
1879	Dudley, Charles Benj., Ph.D.	Box 156, Altoona, Blair Co., Pa.
1886	Duncan, Louis, Ph.D., U.S.N.	56 Pine St., New York, N. Y.
1867	Dunning, George F.	500 Madison Ave., New York, N. Y.
1873	DuPont, Edouard	Royal Museum, Brussels, Belgium.
1894	DuPont, Col. Henry A.	Winterthur, Del.
1871	Dutton, Maj. Clarence E., U.S.A.	Englewood, N. J.
1880	Eckfeldt, Jacob B.	U. S. Mint, Philadelphia.
1877	Eddy, Prof. H. Turner	University of Minnesota, Minneapolis, Minn.
1896	Edison, Thomas Alva, Ph.D.	Orange, N. J.
1895	Edmunds, Hon. George F.	Aiken, S. C.
1906	Edsall, David Linn, M.D.	1432 Pine St., Philadelphia.
1871	Eliot, Pres't Charles W.	17 Quincy St., Cambridge, Mass.
1895	Elliott, Prof. A. Marshall	Johns Hopkins University, Baltimore, Md.
1897	Ely, Theodore N.	115 Broad St. Station, Phila.
1897	Emerson, Prof. Benj. Kendall	Amherst, Mass.
1898	Emmet, W. L. R.	48 Washington Ave., Schenectady, N. Y.
1883	Emmons, Prof. S. F.	1721 H St., Washington, D. C.
1906	Engler, Adolf, Ph.D.	Botanisch. Garten, Berlin—Dahlem, Germany.
1907	d'Estournelles de Constant, Baron	Paris, France.
1881	Evans, Sir John, K.C.B.	Britwell, Berkhamsted, Herts, England.
1895	Ewell, Marshall D., M.D., LL.D.	59 Clark St., Chicago, Ill.
1905	Farlow, Prof. William Gilson	24 Quincy St., Cambridge, Mass.
1895	Fennell, C. A. M., Litt.D.	139 Chesterton Road, Cambridge, England.
1890	Field, Robert Patterson	The Normandie, 36th and Chestnut Sts., Philadelphia.
1897	Fine, Prof. Henry B.	Princeton, N. J.
1897	Fisher, Sydney George, LL.D.	328 Chestnut St., Phila.
1901	Flexner, Simon, M.D.	Rockefeller Institute, 50th and Lexington Ave., New York, N. Y.
1880	Flint, Austin, M.D.	118 E. 19th St., New York, N. Y.

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1891	FORBES, Prof. GEORGE, F.R.S.	34 Great George St., S. W., London, England.
1907	FOSTER, GEORGE CAREY, F.R.S.	Ladywalk, Rickmansworth, Herts, England.
1880	FRALEY, JOSEPH C.	1833 Pine St., Philadelphia.
1904	FRANCKE, Prof. KUNO, Ph.D.	Harvard University, Cambridge, Mass.
1872	FRAZER, PERSIFOR, Dr.	928 Spruce St., Philadelphia.
1905	FRAZIER, CHARLES HARRISON, M.D.	1724 Spruce St., Philadelphia.
1889	FRIEBIS, GEORGE, M D.	1906 Chestnut St., Phila.
1890	FULLERTON, Rev GEORGE S.	Columbia University, New York, N. Y
1873	FULTON, Hon. JOHN	136 Park Pl., Johnstown, Pa.
1880	FURNESS, HORACE HOWARD, LL.D.	Wallingford, Del. Co., Pa.
1897	FURNESS, HORACE HOWARD, JR.	2034 DeLancey Place, Phila.
1897	FURNESS, WILLIAM H., 3d, M.D.	The Warwick, 1906 Sansom St., Philadelphia.
1886	GATES, MERRILL E., LL.D.	1315 New Hampshire Ave., Washington, D. C.
1880	GEIKIE, SIR ARCHIBALD	Shepherd's Down, Haslemere, Sussex, England.
1876	GEIKIE, Prof. JAMES	83 Colinton Rd. Edinburgh, Scotland.
1886	GENTH, Prof. F. A., JR.	222 Walnut St., Phila.
1854	GIBBS, Prof. OLIVER WOLCOTT	158 Gibbs Ave., Newport, R. I.
1901	GIGLIOLI, Prof. HENRY H.	19 Via Romanæ, Florence, Italy.
1902	GILBERT, GROVE KARL, LL.D.	U. S. Geological Survey, Washington, D. C.
1903	GILDERSLEEVE, Prof. BASIL L., LL.D.	1002 Belvidere Terrace, Baltimore, Md.
1867	GILL, THEODORE N., M.D., Ph.D.	Smithsonian Institution, Washington, D. C.
1876	GILMAN, DANIEL C., LL.D.	614 Park Ave., Baltimore, Md.
1895	GLAZEBROOK, RICHARD T., F.R.S.	Bushey House, Teddington, Middlesex, Eng.
1907	GOOCH, FRANK AUSTIN, Ph.D.	New Haven, Conn.
1893	GOODALE, Prof. GEORGE LINCOLN	5 Berkeley St., Cambridge, Mass.
1896	GOODSPEED, Prof. ARTHUR W.	Univ. of Pennsylvania, Phila.
1892	GOODWIN, HAROLD	133 S. 12th St., Philadelphia.
1895	GOODWIN, Prof. W. W.	Cambridge, Mass.
1900	GRAY, GEORGE, Hon.	Wilmington, Del.
1904	GREELY, GEN. ADOLPHUS W., U.S.A.	1914 G St., Washington, D. C.
1893	GREEN, SAMUEL A., M.D.	Massachusetts Historical Soc., Boston, Mass.
1879	GREENE, WILLIAM H., M.D.	N. E. Cor. Arch and 16th Sts., Philadelphia.

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1899	GREENMAN, MILTON J., M.D.	Wistar Institute, 36th St. and Woodland Ave., Phila.
1888	DE GREGORIO, MARQUIS ANTONIO	Al Molo, Palermo, Sicily.
1891	GREGORY, Prof. CASPAR RENÉ	Naunhoferstrasse 5 Marienhöhe, Leipzig-Stötteritz, Germany.
1907	GRIFFITH, J. P. CROZER, M.D.	1810 Spruce St., Philadelphia.
1886	DE GUBERNATIS, Prof. ANGELO	Florence, Italy.
1903	GUMMERE, Prof. FRANCIS BARTON, Ph.D	Haverford College, Haverford, Pa.
1902	HADLEY, Pres't ARTHUR T.	Yale University, New Haven, Conn.
1885	HAECKEL, Prof. Dr. ERNST	University, Jena, Germany.
1903	HAGUE, ARNOLD, D.Sc	1724 I St., Washington, D. C.
1870	HALE, REV. EDWARD EVERETT	39 Highland St., Roxbury, Mass.
1902	HALE, Prof. GEORGE E.	Solar Observatory Office, Pasadena, Cal.
1875	HALL, CHARLES EDWARD	Instituto Geologico de Mexico, Santa Maria, Mexico, Mex.
1898	HALL, CHARLES M.	136 Buffalo Ave., Niagara Falls, N. Y.
1885	HALL, Prof. LYMAN B.	Haverford Coll., Haverford, Pa.
1891	HAMY, Dr. ERNST T.	36, Rue Geoffroy-St-Hilaire, Pavillon de Buffon, Paris, France.
1887	HARRIS, JOSEPH S.	144 School Lane, Germantown, Philadelphia.
1895	HARRISON, Provost CHARLES C.	400 Chestnut St., Phila.
1906	HARSHBERGER, JOHN W., Ph.D.	4839 Walton Ave., Phila.
1877	HART, Prof. JAMES MORGAN	1 Reservoir Ave., Ithaca, N. Y.
1906	HASTINGS, Prof. CHARLES S., Ph.D.	248 Bradley St., New Haven, Conn.
1878	HAUPT, Prof. LEWIS M.	107 N. 35th St., Philadelphia.
1902	HAUPT, Prof. PAUL	2511 Madison Ave., Baltimore.
1886	HAYS, I. MINIS, M.D.	266 S. 21st St., Philadelphia.
1893	HEWETT, Prof. WATERMAN T.	31 East Ave., Ithaca, N. Y.
1895	HEYSE, PAUL, Ph.D.	Munich, Bavaria.
1903	HILL, GEORGE WILLIAM, LL.D.	West Nyack, N. Y.
1906	HILLEBRAND, WILLIAM FRANCIS, Ph.D.	506 T St., N. W., Washington, D. C.
1897	HILLER, H. M., M.D.	Kohoka, Mo.

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1886	HILPRECHT, Prof. HERMANN V., Ph.D.	Free Museum of Art, Univ. of Penn., Phila.
1874	HIMES, Prof. CHARLES FRANCIS, Ph.D.	170 W. Louther St., Carlisle, Pa.
1899	HIRST, BARTON COOKE, M.D.	1821 Spruce St., Philadelphia.
1870	HITCHCOCK, Prof. CHAS. HENRY	Dartmouth College. Hanover, N. H.
1897	HOLDEN, Prof. EDWARD S.	U. S. Military Academy, West Point, N. Y.
1886	HOLLAND, JAMES W., M.D.	2006 Chestnut St., Phila.
1899	HOLMES, Prof. WILLIAM H.	Bureau of Ethnology, Smithsonian Institution, Washington, D. C.
1869	HOOKER, SIR JOSEPH DALTON, G.C.S.I.	The Camp, Sunningdale, Eng.
1886	HORNER, INMAN	1811 Walnut St., Phila.
1872	HOUGH, Prof. GEORGE W.	Northwestern University, Evanston, Ill.
1872	HOUSTON, Prof. EDWIN J.	4619 Chester Ave., Phila.
1897	HOWE, Prof. HENRY M.	27 W. 73d St., New York City.
1903	HOWELL, Prof. WILLIAM HENRY	232 W. Lanvale St., Baltimore, Md.
1895	HUGGINS, SIR WILLIAM, K.C.B.	90 Upper Tulse Hill, S. W., London, England.
1877	HUMPHREY, H. C.	The New York Glucose Co., Edgewater, Bergen Co., N. J.
1895	HUNTER, RICHARD S.	1413 Locust St., Phila.
1898	HUTCHINSON, EMLEN	Aldine Hotel, Philadelphia.
1875	INGHAM, WM. ARMSTRONG	320 Walnut St., Phila.
1893	D'INVILLIERS, EDWARD VINCENT	506 Walnut St., Phila.
1884	JAMES, Pres't EDMUND J.	Urbana, Ill.
1897	JASTROW, Prof. MORRIS, JR.	248 S. 23d St., Philadelphia.
1898	JAYNE, HENRY LABARRE	1035 Spruce St., Philadelphia.
1885	JAYNE, HORACE, M.D.	318 S. 19th St., Philadelphia.
1907	JENNINGS, HERBERT SPENCER, Ph.D.	Johns Hopkins University, Baltimore, Md.
1905	JORDAN, Pres't DAVID STARR	Stanford Univ., Cal.
1884	JORDAN, FRANCIS, JR.	111 N. Front St., Phila.
1907	JUSSERAND, JEAN ADRIEN ANTOINE JULES, LL.D.	French Embassy, Washington, D. C.
1883	KANE, ELISHA KENT	Kushequa, Pa.
1907	KAPTEYN, Prof. JOHN C.	Groningen, Holland.
1897	KARPINSKY, Prof. ALEX. PETROVITCH	Geological Survey, St. Petersburg, Russia.

Elected.	*Name.*	*Present Address.*
1889	Keane, Right Rev. John J.	Dubuque, Iowa.
1899	Keasbey, Prof. Lindley M., Ph.D.	1802 Colorado St., Austin, Texas.
1897	Keen, Gregory B.	3237 Chestnut St., Phila.
1884	Keen, William W., M.D., LL.D.	1729 Chestnut St., Phila.
1898	Keiser, Prof. Edward H., Ph.D.	Washington University, St. Louis, Mo.
1900	Keller, Prof. Harry F.	Central High School, Phila.
1896	Kennelly, A. E., D.Sc.	Harvard University, Cambridge, Mass.
1905	Kittredge, George Lyman, LL.D.	8 Hilliard St., Cambridge, Mass.
1898	Knight, Prof. William A.	Malvern, England.
1874	König, Prof. George A., Ph.D.	School of Mines, Houghton, Mich.
1899	Kraemer, Prof. Henry	145 N. 10th St., Philadelphia.
1889	Krauss, Friedrich S., Ph.D.	VII^2 Neustiftgasse 12, Vienna, Austria.
1872	Lambert, Prof. Guillaume	42 Boulevard Bischoffsheim, Brussels, Belgium.
1904	Lambert, Prof. Preston A.	Lehigh University, Bethlehem, Pa.
1899	Lamberton, Prof. William A.	University of Penna., Phila.
1897	Lanciani, Prof. Rodolfo	2 Via Goito, Rome, Italy.
1878	Landreth, Burnet	Bristol, Pa.
1903	Lankester, Edwin Ray, LL.D., F.R.S.	British Museum, Cromwell Rd., London, S. W., Eng.
1906	Lanman, Prof. Charles Rockwell, LL.D.	9 Farrar St., Cambridge, Mass.
1867	Lea, Henry Charles, LL.D.	2000 Walnut St., Phila.
1899	Learned, Prof. Marion D.	University of Penna., Phila.
1905	LeConte, Robert G., M.D.	1625 Spruce St., Phila.
1883	Lehman, Ambrose E.	425 Chestnut St., Lebanon, Pa.
1889	Le Moine, Sir James M.	Spencer Grange, Quebec, Can.
1881	Leroy-Beaulieu, Prof. Paul	27 Ave. du Bois de Boulogne, Paris, France.
1886	Levasseur, Prof. Emile	26 Rue Mons. le Prince, Paris, France.
1896	Lewis, G. Albert	1834 DeLancey Place, Phila.
1897	Libbey, Prof. William	20 Bayard Ave., Princeton, N.J.
1897	Lister, Right Hon. Joseph, Lord	12 Park Crescent, Portland Place, London, England.

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1874	LOCKYER, SIR JOSEPH NORMAN, K.C.B., F.R.S.	Royal College of Science, S. Kensington, London, S. W., England.
1901	LODGE, SIR OLIVER JOSEPH, LL.D., F.R.S.	The University, Birmingham, England.
1899	LOEB, Dr. JACQUES	University of California, Berkeley, Cal.
1878	LONGSTRETH, MORRIS, M.D.	1416 Spruce St., Phila.
1906	LORENTZ, Dr. HENDRIK ANTON	University of Leyden, Leyden, Holland.
1904	LOVETT, Prof. EDGAR ODELL, LL.D.	Princeton, N. J.
1892	LOW, HON. SETH	30 E. 46th St., New York, N. Y.
1897	LOWELL, PERCIVAL	53 State St., Boston, Mass.
1869	LYMAN, BENJAMIN SMITH	708 Locust St., Phila.
1897	MABERY, Prof. CHARLES F.	57 Adelbert St., Cleveland, O.
1886	MACALISTER, Pres't JAMES	4031 Walnut St., Phila.
1897	McCAY, Prof. LEROY W.	257 Nassau St., Princeton, N.J.
1897	McCLURE, Prof. CHARLES F. W.	Princeton, N. J.
1896	McCOOK, Rev. HENRY C., D.D.	Devon, Pa.
1879	McCREATH, ANDREW S.	121 Market St., Harrisburg, Pa.
1892	MACFARLANE, Prof. JOHN M.	Univ. of Pennsylvania, Phila.
1899	MACKENZIE, Prof. ARTHUR S., Ph.D.	Dalhousie University, Halifax, Nova Scotia.
1907	McMURRICH, Prof. JAMES PLAYFAIR	University of Toronto, Toronto, Canada.
1896	MAGIE, Prof. WM. FRANCIS, Ph.D.	Princeton, N. J.
1897	MAHAN, Capt. ALFRED T., U.S.N.	160 W. 86th St., New York.
1906	MALL, FRANKLIN PAINE, M.D., LL.D.	1514 Bolton St., Baltimore, Md.
1885	MALLET, Prof. JOHN WM., M.D.	University of Virginia, Charlottesville, Va.
1878	MANSFIELD, IRA FRANKLIN	Beaver, Beaver Co., Pa.
1895	MANTEGAZA, Sig. PAOLO	Florence, Italy.
1878	MARCH, Prof. FRANCIS ANDREW	Lafayette College, Easton, Pa.
1901	MARCONI, GUGLIELMO	18 Finch Lane, E. C., London, England.
1907	MARK, Prof. EDWARD LAURENS, LL.D.	109 Irving St., Cambridge, Mass.
1878	MARKS, Prof. WILLIAM D.	218 The Bourse, Philadelphia.

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1886	Marshall, John, M.D.	1718 Pine St., Philadelphia.
1890	Mascart, Prof. E.	16 Rue Christophe Colomb. Paris, France.
1867	Mason, Andrew	30 Wall St., New York City.
1899	Mason, Prof. Otis T.	U. S. National Museum, Washington, D. C.
1896	Mason, Prof. Wm. Pitt, M.D.	Rensselaer Polytechnic Institute, Troy, N. Y.
1891	Maspero, Prof. Gaston-Camille	Collège de France, Paris, France.
1899	Matthews, Albert	483 Beacon St., Boston, Mass.
1899	Meigs, Arthur V., M.D.	1322 Walnut St., Phila.
1901	Meigs, William M.	1815 Pine St., Phila.
1886	von Meltzel, Prof. Dr. Hugo	Koloszvar, Hungary.
1897	Melville, Rear Admiral Geo. W., U. S. N.	615 Walnut St., Philadelphia.
1899	Mendenhall, Prof. Thomas C.	Worcester, Mass.
1898	Mengarini, Prof. Dott. Guglielmo	Rome, Italy.
1895	Mercer, Henry C.	Doylestown, Pa.
1902	Merriam, Dr. C. Hart	1919 16th St., Washington, D. C.
1881	Merriman, Prof. Mansfield	32 West 40th St., New York, N. Y.
1899	Meyer, Prof. A. B.	Hohenzollernstrasse 17, Berlin, W. 10, Germany.
1902	Michelson, Prof. Albert A., F.R.S.	Univ. of Chicago, Chicago, Ill.
1899	Miller, Prof. Leslie W.	N. W. cor. Broad and Pine Sts., Philadelphia.
1896	Minot, Chas. Sedgwick, M.D.	Harvard Medical School, Boston, Mass.
1890	Mitchell, Hon. James T.	1722 Walnut St., Phila.
1862	Mitchell, S. Weir, M.D.	1524 Walnut St., Phila.
1898	Montgomery, Prof. Thos. H., Jr.	Univ. of Texas, Austin, Texas.
1897	Moore, Clarence B.	1321 Locust St., Phila.
1905	Moore, Prof. Eliakim H.	Univ. of Chicago, Chicago, Ill.
1905	Moore, George T., Ph.D.	Water Mill, N. Y.
1885	Moore, Prof. James W., M.D.	Lafayette College, Easton, Pa.
1907	Moore, John Bassett, LL.D.	267 W. 73d St., New York, N. Y.
1903	Morley, Edward W., LL.D.	West Hartford, Conn.
1897	Morley, Prof. Frank	Johns Hopkins University, Baltimore, Md.
1899	Morris, Harrison S.	Oak Lane P. O., Philadelphia.
1899	Morris, Israel W.	225 S. 8th St., Philadelphia.
1883	Morris, J. Cheston, M.D.	1514 Spruce St., Philadelphia.

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1901	MORRIS, JOHN T.	876 Drexel Building, Phila.
1895	MORSE, Prof. EDWARD S.	Essex Institute, Salem, Mass.
1903	MORSE, HARMON N., Ph.D.	1117 N. Eutaw St., Baltimore, Md.
1886	MUCH, Prof. MATHÆUS, Ph.D.	XIII² Penzingerstrasse, 84, Vienna, Austria.
1901	MUNRO, Prof. DANA C.	University of Wisconsin, Madison, Wis.
1891	MUNROE, Prof. CHARLES E.	Columbian University, Washington, D. C.
1886	MURDOCK, Com. J. B., U.S.N.	Navy Dept., Washington, D. C.
1881	MURRAY, JAMES A. H., LL.D.	Sunnyside, Banbury Road, Oxford, England.
1897	NANSEN, Prof. FRIDTJOF	Godthaab, Lysaker, Norway.
1878	NEWCOMB, Prof. SIMON, F.R.S.	1620 P St., N. W., Washington, D. C.
1904	NICHOLS, Prof. EDWARD L., Ph.D.	Cornell Univ., Ithaca, N. Y.
1906	NICHOLS, ERNEST FOX, D.Sc.	Columbia University, New York, N. Y.
1872	NICHOLS, Rev. STARR HOYT	128 Main St., Danbury, Conn.
1866	NIKITIN, Prof. SERGI	Geological Survey, St. Petersburg, Russia.
1907	NIPHER, Prof. FRANCIS EUGENE	1220 Hamilton Ave., St. Louis, Mo.
1906	NÖLDEKE, Prof. THEODOR, Ph.D.	University of Strassburg, Strassburg, Germany.
1905	NORDENSKJÖLD, Prof. OTTO	Goteborg 3, Sweden.
1872	NORRIS, ISAAC, M.D.	Fair Hill, Bryn Mawr, Pa.
1895	NUTTALL, MRS. ZELIA	Casa de Alvarado, Coyoacán, D. F. Mexico.
1886	OLIVER, CHARLES A., M.D.	1507 Locust St., Phila.
1897	OLNEY, Hon. RICHARD	23 Court St., Boston, Mass.
1897	ORTMANN, Prof. ARNOLD E., Ph.D.	Carnegie Museum, Annex, 419 Craft Ave., Pittsburg, Pa.
1887	OSBORN, Prof. HENRY F., LL.D.	American Museum of Natural History, New York, N. Y.
1885	OSLER, Prof. WILLIAM, M.D.	13 Norham Gardens, Oxford, Eng.
1898	PANCOAST, HENRY S.	78 Vernon St., Hartford, Conn.
1885	PATTERSON, C. STUART	1000 Walnut St., Phila.
1900	PATTERSON, Hon. EDWARD	Supreme Court, Appellate Div., 1st Dept., New York City.
1898	PATTERSON, LAMAR GRAY	Guano, Amherst Co., Va.
1851	PATTERSON, ROBERT	329 Chestnut St., Phila.
1897	PATTON, Pres't FRANCIS L., D.D.	Princeton, N. J.
1899	PAUL, J. RODMAN	903 Pine St., Philadelphia.
1875	PEARSE, JOHN B.	317 Walnut Ave., Roxbury, Mass.

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1873	Pemberton, Henry	1947 Locust St., Phila.
1886	Peñafiel, Dr. Antonio	City of Mexico, Mexico.
1901	Penniman, Prof. Josiah H.	4326 Sansom St., Phila.
1886	Pennypacker, Hon. Samuel W.	Schwenksville, Pa.
1863	Penrose, R. A. F., M.D.	1331 Spruce St., Phila.
1905	Penrose, R. A. F., Jr., Ph.D.	460 Bullitt Bld'g, Phila.
1886	Pepper, Edward, M.D.	Care of Drexel, Harjes & Co., 31 Boulevard, Haussmann, Paris, France.
1897	Pepper, George Wharton, LL.D.	701 Drexel Building, Phila.
1905	Petrie, W. M. Flinders, D.C.L., LL.D., F.R.S.	University College, Gower St., W. C., London, Eng.
1895	Pettit, Henry	Pelican Lodge, West Palm Beach, Florida.
1899	Phillips, Prof. Francis C.	P. O. Box 126, Allegheny, Pa.
1896	Pickering, Prof. Edw. C.	Harvard University, Cambridge, Mass.
1897	Piersol, George A., M.D.	Chester Ave. and 49th St., Philadelphia.
1895	Pilsbry, Prof. Henry A.	Academy of Natural Sciences, Philadelphia.
1898	Platt, Charles	237 S. 18th St., Phila.
1899	Poincaré, Prof. Henri	63 Rue Claude Bernard, Paris, France.
1886	Postgate, Prof. John P.	Cambridge, England.
1899	Preece, Sir Wm. Henry, K.C.B., F.R.S.	13 Queen Anne's Gate, London, S. W., England.
1875	Prime, Frederick	1008 Spruce St., Phila.
1899	Pritchett, Henry S., LL.D.	22 E. 91st St., New York, N. Y.
1874	Pumpelly, Prof. Raphael	Newport, R. I.
1896	Pupin, Prof. Michael I.	7 Highland Pl., Yonkers, N. Y.
1895	Putnam, Prof. Frederick W.	Peabody Museum, Cambridge, Mass.
1899	Ramsay, Sir William, K.C.B., F.R.S.	University College, Gower St., W. C. London, Eng.
1901	Ravenel, Mazÿck P., M.D.	University of Wisconsin, Madison, Wis.
1898	Rawle, Francis	328 Chestnut St., Phila.
1899	Rawle, William Brooke	230 S. 22d St., Phila.

Elected.	Name.	Present Address.
1886	RAYLEIGH, Right Hon. JOHN WILLIAM STRUTT, Lord	Terling Pl., Witham, Essex, England.
1875	RAYMOND, Capt. ROSSITER W.	29 W. 39th St., New York, N. Y.
1898	REDWOOD, Sir BOVERTON, F.R.S.	4, Bishopsgate St. Within, E. C., London, England.
1899	REMINGTON, Prof. JOSEPH, P.	1832 Pine St., Phila.
1879	REMSEN, President IRA	Johns Hopkins University, Baltimore, Md.
1907	RICHARDS, HORACE CLARK, Ph.D.	University of Pennsylvania, Philadelphia.
1902	RICHARDS, Prof. THEO. WILLIAM	15 Follen St., Cambridge, Mass.
1882	ROBINS, Rev. JAMES W., D.D.	2115 Pine St., Phila.
1890	ROGERS, Prof. ROBERT W.	Drew Theological Seminary, Madison, N. J.
1862	RÖHRIG, Prof. F. L. OTTO	402 S. Oakland Ave., Pasadena, Cal.
1907	ROLFE, JOHN C., Ph.D.	University of Pennsylvania, Philadelphia.
1904	ROOSEVELT, HON. THEODORE	The White House, Washington, D. C.
1906	ROOT, HON. ELIHU	Department of State, Washington, D. C.
1903	ROSCOE, SIR HENRY E., F.R.S., D.C.L.	Woodcote Lodge, West Horsley, Leatherhead, England.
1891	ROSENGARTEN, JOSEPH G., LL.D.	1704 Walnut St., Phila.
1882	DE ROSNY, Prof. LÉON	28 Rue Mazarin, Paris, France.
1877	ROTHROCK, JOSEPH T., M.D.	West Chester, Pa.
1904	RUTHERFORD, Prof. ERNEST, F.R.S.	University of Manchester, Manchester, England.
1894	SACHSE, JULIUS F., Litt.D.	4428 Pine St., Phila.
1874	SADTLER, Prof. SAMUEL P.	N. E. cor. 10th and Chestnut Sts., Philadelphia.
1888	SAJOUS, CHARLES E., M.D.	2043 Walnut St., Phila.
1897	SAMPSON, ALDEN	2223 Atherton St., Berkeley, Cal.
1897	SANDERS, RICHARD H.	1225 Locust St., Phila.
1882	SARGENT, Prof. CHARLES SPRAGUE	Jamaica Plain, Mass.
1902	SCHELLING, Prof. FELIX E., Ph.D.	4211 Sansom St., Phila.
1901	SCHIAPARELLI, Prof. GIOVANNI	Royal Observatory, Milan, Italy.
1873	SCLATER, PHILIP LUTLEY, Ph.D., F.R.S.	3 Hanover Square, London, W., England.

Elected.	Name.	Present Address.
1898	Scott, Charles F.	Westinghouse Electric Co., Pittsburg, Pa.
1886	Scott, Prof. William B.	Princeton, N. J.
1878	Scudder, Samuel Hubbard	Cambridge, Mass.
1897	See, Thomas J. J., LL.D.	Observatory, Mare Island, Cal.
1899	Sellers, Coleman, Jr.	410 N. 33d St., Phila.
1885	Sergi, Prof. Giuseppe	Università Romana, Rome, Italy.
1886	Sharp, Benjamin, M.D.	Academy of Natural Sciences, Philadelphia.
1882	Sharples, Prof. Stephen Paschall	26 Broad St., Boston, Mass.
1875	Sherwood, Andrew	Montavilla, Portland, Oregon.
1899	Sigsbee, Admiral Charles D., U.S.N.	Navy Dept., Washington, D. C.
1900	Sinkler, Wharton, M.D.	1606 Walnut St., Phila.
1897	Smith, A. Donaldson, M.D.	1811 Walnut St., Phila.
1907	Smith, Allen J., M.D.	University of Pennsylvania, Philadelphia.
1887	Smith, Prof. Edgar F.	Univ. of Pennsylvania, Phila.
1875	Smith, Stephen, M.D.	57 W. 42d St., New York, N. Y.
1897	Smock, Prof. John C.	Trenton, N. J.
1894	Snellen, Herman, Jr., Ph.D.	Utrecht, Netherlands.
1873	Snowden, A. Loudon, LL.D.	1812 Spruce St., Phila.
1884	Snyder, Prof. Monroe B.	2402 N. Broad St., Phila.
1873	Spofford, A. R., LL.D.	Library of Congress, Washington, D. C.
1903	Stengel, Alfred, M.D.	1811 Spruce St., Phila.
1897	Stephens, Prof. H. Morse	University of California, Berkeley, Cal.
1884	Stevens, Prof. Walter LeConte	Lexington, Va.
1877	Stevenson, Prof. John James	Univ. Heights, New York City.
1895	Stevenson, Sara Y., Sc.D.	237 S. 21st St., Philadelphia.
1898	Stillwell, Lewis B.	Sixth St., Lakewood, N. J.
1902	Stoney, Prof. G. Johnstone, F.R.S.	30 Ledbury Road, Bayswater, London, W., England.
1904	Stratton, Prof. Samuel W.	Bureau of Standards, Washington, D. C.
1886	Suess, Prof. Edouard	K. K. Geologische Reichsanstalt, Vienna, Austria.
1895	Sulzberger, Hon. Mayer	1303 Girard Ave., Phila.
1886	Szombathy, Prof. Josef	Burgring 7, Vienna, Austria.
1897	Tatham, William	1811 Walnut St., Phila.
1886	Temple, Lt.-Col. Sir Richard Carnac	The Nash, Worcester, Eng.
1896	Tesla, Nikola, LL.D.	Wardenclyffe, Long Island, N. Y.

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1905	THISELTON-DYER, SIR WILLIAM T., K.C.M.G.	The Ferns, Witcombe, Gloucester, England.
1884	THOMAS, Prof. ALLEN C.	Haverford, Pa.
1884	THOMPSON, HEBER S.	Sheafer Build'g, Pottsville, Pa.
1902	THOMPSON, Prof. SILVANUS P., F.R.S.	Technical College, Finsbury, Leonard St., City Road, London, E. C., England.
1876	THOMSON, Prof. ELIHU	22 Monument Ave., Swampscott, Mass.
1903	THOMSON, JOSEPH JOHN, D.Sc., F.R.S.	Trinity Coll., Cambridge, Eng.
1885	IM THURN, EVERARD F.	Govt. House, Sura, Fiji, Western Pacific.
1902	TILGHMAN, BENJAMIN CHEW	1126 S. 11th St., Phila.
1906	TITCHENER, Prof. EDWARD BRADFORD, Ph.D.	Cornell Heights, Ithaca, N. Y.
1906	TITTMANN, OTTO HILGARD	2014 Hillyer Place, Washington, D. C.
1886	TOPINARD, Prof. Dr. PAUL	105 Rue de Rennes, Paris, France.
1895	TOWER, Hon. CHARLEMAGNE, JR., LL.D.	American Embassy, Berlin, Germany.
1903	TRELEASE, WILLIAM, Sc.D.	Missouri Botanical Garden, St. Louis, Mo.
1899	TREVELYAN, Rt. Hon. Sir GEORGE OTTO	8 Grosvenor Crescent, S. W. London, England.
1896	TROWBRIDGE, Prof. JOHN	Harvard University, Cambridge, Mass.
1899	TRUE, Dr. FREDERICK WILLIAM	U. S. National Museum, Washington, D. C.
1882	TSCHERMAK, GUSTAV	Universität, Vienna, Austria.
1897	TSCHERNYSCHEW, Prof. THEODORE	Geological Survey, St. Petersburg, Russia.
1907	TURNER, SIR WILLIAM, K.C.B., F.R.S.	6 Eton Terrace, Edinburgh, Scotland.
1890	TURRETTINI, Prof. THEODORE	Geneva, Switzerland.
1889	TUTTLE, DAVID K., Ph.D.	U. S. Mint, Philadelphia.
1889	TYLER, Hon. LYON G., Pres't	Williamsburg, Va.
1887	TYSON, JAMES, M.D.	1506 Spruce St., Phila.
1890	UNWIN, Prof. WILLIAM C.	7 Palace Gate Mansions, London, England.
1904	VAN'T HOFF, Prof. JAKOB H.	Univ. of Berlin, Berlin, Ger.

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1905	VENABLE, Pres't FRANCIS P., LL.D.	Chapel Hill, N. C.
1870	VOSE, Prof. GEORGE L.	Brunswick, Maine.
1903	DE VRIES, Prof. HUGO	University of Amsterdam, Amsterdam, Netherlands.
1885	WAGNER, SAMUEL	Greenbank Farm, West Chester, Pa.
1874	WAHL, WILLIAM H., Ph.D.	15 S. 7th St., Philadelphia.
1897	WALCOTT, CHARLES D., LL.D.	Smithsonian Institution, Washington, D. C.
1904	WALDEYER, Prof. WILHELM	56 Luisenstrasse, Berlin, N. W., 6, Germany.
1873	WALLACE, ALFRED RUSSEL, LL.D.	Broadstone, Wimborne, Eng.
1889	WARD, LESTER F., LL.D.	Brown University, Providence, R. I.
1881	WARE, LEWIS S.	54 Rue de la Bienfaisance, Paris, France.
1897	WARFIELD, Pres't ETHELBERT D.	Easton, Pa.
1906	WEBSTER, ARTHUR GORDON, Ph.D.	66 West St., Worcester, Mass.
1906	WEISMANN, Prof. AUGUST	Stadt Strasse 4, Freiburg (I. Br.), Baden, Germany.
1896	WELCH, Prof. WILLIAM H., M.D.	807 St. Paul St., Baltimore, Md.
1869	WHARTON, JOSEPH	P. O. Box 1332, Phila.
1869	WHITE, Hon. ANDREW D.	White Library, Cornell Univ., Ithaca, N. Y.
1878	WHITE, Prof. ISRAEL C.	119 Wiley St., Morgantown, W. Va.
1905	WHITFIELD, J. EDWARD	406 Locust St., Phila.
1898	WHITFIELD, Prof. R. P.	American Museum of Natural History, New York, N. Y.
1899	WHITMAN, Prof. CHARLES OTIS, Ph.D., LL.D.	Univ. of Chicago, Chicago, Ill.
1878	WILDER, Prof. BURT G.	McGraw Hall, Ithaca, N. Y.
1904	WILEY, HARVEY W., M.D., LL.D.	U. S. Dept. of Agriculture, Washington, D. C.
1895	WILLCOX, JOSEPH	"The Clinton," 10th and Clinton Sts., Philadelphia.
1897	WILLIAMS, Prof. EDWARD H., JR.	53 Phillips St., Andover, Mass.
1888	WILLIAMS, TALCOTT, LL.D.	916 Pine St., Phila.
1905	WILLIS, BAILEY	U. S. Geological Survey, Washington, D. C.
1890	WILLIS, Prof. HENRY	4036 Baring St., Phila.
1885	WILSON, JAMES CORNELIUS, M.D.	1511 Walnut St., Phila.
1887	WILSON, Prof. WILLIAM POWELL, M.D.	Commercial Museum, Phila.

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1897	WILSON, Pres't WOODROW	Prospect, Princeton, N. J.
1897	WISTER, OWEN	328 Chestnut St., Phila.
1897	WITMER, Prof. LIGHTNER, Ph.D.	2426 Spruce St., Phila.
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1899	WOOD, STUART	1620 Locust St., Phila.
1874	WOODWARD, HENRY, LL.D., F.R.S.	13 Arundel Gardens, Notting Hill, London, W., Eng.
1902	WOODWARD, Pres't ROBERT S., Ph.D.	Carnegie Institution, Washington, D. C.
1896	WRIGHT, Prof. ARTHUR W., Ph.D.	73 York Square, New Haven, Conn.
1900	WRIGHT, WILLIAM ALDIS, LL.D., D.C.L.	Trinity Coll., Cambridge, Eng.
1895	WUNDT, Prof. WILLIAM	Leipzig, Germany.
1899	WURTS, ALEXANDER JAY	Carnegie Technical School, Pittsburg, Pa.
1886	WYCKOFF, Lieut. A. B., U.S.N.	Navy Dep't, Washington, D. C.

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1. The candidate shall, on or before November 1, 1908, deliver free of postage or other charges, his discovery, invention or improvement, addressed to the President of the American Philosophical Society, No. 104 South Fifth Street, Philadelphia, U. S. A., and shall distinguish his performance by some motto, device, or other signature. With his discovery, invention, or improvement, he shall also send a sealed letter containing the same motto, device, or other signature, and subscribed with the real name and place of residence of the author.

2. Persons of any nation, sect or denomination whatever, shall be admitted as candidates for this premium.

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